GAMMA-RAY LARGE AREA SPACE TELESCOPE (GLAST)

PROJECT DATA MANAGEMENT PLAN

DRAFT VERSION 14
(Major revision by D. Band 10/03)

October 10, 2003

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

GAMMA-RAY LARGE AREA SPACE TELESCOPE
(GLAST) OBSERVATORY

PROJECT DATA MANAGEMENT PLAN

October 10, 2003

NASA Goddard Space Flight Center

Greenbelt, Maryland

DRAFT—07/08/04

GLAST OBSERVATORY PROJECT DATA MANAGEMENT PLAN

Prepared and maintained by:

David L. Band, Science Lead, GSSC — Date

Concurrence:

Donald A. Kniffen, Program Scientist — Date

Approval:

Jonathan Ormes, GLAST Project Scientist — Date

Kevin Grady, GLAST Project Manager — Date

Peter F. Michelson, LAT Principal Investigator — Date

Charles Meegan, GBM Principal Investigator — Date

Michael Rackley, Ground Systems/ Operations Lead — Date

Nicholas White, HEASARC Director — Date

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CHANGE RECORD PAGE

DOCUMENT TITLE: GLAST Observatory Project Data Management Plan

DOCUMENT DATE: October 10, 2003

ISSUE	DATE	PAGES AFFECTED	DESCRIPTION
DRAFT	7/2/01		
REVISED DRAFT	10/10/03	All	

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ACRONYMS AND ABBREVIATIONS

ACD	Anti-Coincidence Detector
ACS	Attitude Control System
ATC	Absolute Time Command
ATS	Absolute Time Sequence
BAP	Burst Alert Processor
BATSE	Burst and Transient Source Experiment
BGO	Bismuth Germanate
CADH	Command And Data Handling
CAL	Calorimeter
CALDB	Calibration DataBase
CCSDS	Consultative Committee on Space Data Systems
CGRO	Compton Gamma-Ray Observatory
DAQ	Data Acquisition System
DAS	Demand Access System
DPU	Data Processing Unit
EGRET	Energetic Gamma Ray Experiment Telescope
EPDS	Electrical Power and Distribution System
ETR	Eastern Test Range
FITS	Flexible Image Transport System
FOT	Flight Operations Team
FOV	Field-of-View
GBM	GLAST Burst Monitor
GCN	Gamma-ray burst Coordinates Network

GI	Guest Investigator
GIOC	GBM Instrument Operations Center
GLAST	Gamma-ray Large Area Space Telescope
GN	Ground Network
GRB	Gamma-Ray Burst
GSFC	Goddard Space Flight Center
GSSC	GLAST Science Support Center
HEASARC	High Energy Astrophysics Science Archive Research Center
HQ	Headquarters
ICD	Interface Control Document
IDS	Interdisciplinary Scientist
IOC	Instrument Operations Center
IRF	Instrument Response Function
IRSA	Infrared Science Archive
LAT	Large Area Telescope
LHEA	Laboratory for High Energy Astrophysics
LIOC	LAT Instrument Operations Center
MAS	Multiple Access System
MAST	Multimission Archive at Space Telescope science institute
MOC	Mission Operations Center
MPE	Max Planck Institute for Extraterrestrial Physics
NaI	Sodium Iodide
NASA	National Aeronautics and Space Administration
NRA	NASA Research Announcement
NSSDC	National Space Science Data Center

NSSTC	National Space Science and Technology Center
OGIP	Office of Guest Investigator Programs
PDB	Project Database
PDMP	Project Data Management Plan
PI	Principal Investigator
PIL	Parameter Interface Layer
PMT	Photomultiplier Tube
SAA	South Atlantic Anomaly
SN	Space Network
SU	Stanford University
SU-SLAC	Stanford University-Stanford Linear Accelerator Center
SSD	Silicon Strip Detector
SSR	Solid State Recorder
SWG	Science Working Group
RTS	Relative Time Sequence
TBD	To Be Determined
TBR	To Be Reviewed
TDRSS	Tracking and Data Relay Satellite System
TKR	Tracker
TLM	Telemetry
TOO	Target of Opportunity
TT	Terrestrial Time
USRA	Universities Space Research Association
WSC	White Sands Complex

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1 INTRODUCTION

1.1 PURPOSE AND SCOPE

This Gamma-ray Large Area Space Telescope (GLAST) Project Data Management Plan (PDMP) describes the activities of the GLAST Project for processing, analyzing, and archiving the data acquired by the Observatory for all phases of the mission. This includes plans for the integration of the GLAST data environment with other elements of the NASA astrophysics data infrastructure. The PDMP also specifies the mechanisms for disseminating data, software, results and supporting documentation, in a timely and orderly manner, to the wider scientific community, and for providing expertise to support the scientific community's use of the GLAST data.

The PDMP articulates the policy of the GLAST Project for processing, formatting, storing, accessing, archiving, and distributing all GLAST data. It presents milestones for reducing and interpreting the data, and specifies the conditions for discarding the mission data. The document describes the GLAST Guest Investigator (GI) Program and the roles of the organizations that support the GI Program. It discusses facilities, analysis software development, documentation, support services and data delivery, and archiving requirements and schedule. The PDMP also indicates the interfaces between the GLAST-wide data analysis system and the particle and astrophysics communities, and the requirements that must be met by the integrated system to realize these interfaces successfully.

As opposed to the PDMPs for some other missions, this PDMP leaves the formats of data products exchanged by the ground elements to the appropriate Interface Control Documents (ICDs) and Memoranda of Understanding (MOUs) and operational details to a separate Ground System Operations Agreement. Where appropriate, the text refers to the relevant document. Conversely, for clarity and context this PDMP includes details about the instruments and spacecraft which are covered in greater detail in other documents; specifically, this PDMP is *not* the controlling document for the requirements for instrument capabilities.

The GLAST Science Support Center (GSSC) at NASA's Goddard Space Flight Center (GSFC) supports participation in the GLAST observation program by the general astronomical community for all phases of the mission in a form consistent with other high energy astrophysics missions. A fundamental role of the GSSC is to oversee the creation of the GLAST archive and its delivery to the High Energy Astrophysics Science Archive Research Center (HEASARC). Instrument Operation Centers (IOCs) will be established by the instrument teams for both the Large Area Telescope (LAT) and the GLAST Burst Monitor (GBM). The Mission Operations Center (MOC) at GSFC will be the interface to the spacecraft. The MOC is staffed by the Flight Operations Team (FOT). There may be mirror data sites outside the United States associated with the instrument teams. This PDMP describes the relationship between the MOC, the IOCs, the GSSC, the HEASARC, and the scientific community. In addition, this document establishes the roles, functions and responsibilities with regard to data operations of the MOC, the IOCs, the GSSC and the HEASARC to each other, other elements of the NASA Astrophysics Data infrastructure, the GIs, and the general scientific community. An overview of the GI Program is included, as it affects many of the data flow requirements. Details will be provided in the NASA Research Announcements (NRAs) issued for each phase of the program (approximately annually).

§2 gives an overview of the GLAST mission while §3 describes the two science instruments, their experimental objectives, instrument design, and operation and data modes. §4 presents the different data levels, the end-to-end data flow after launch, and the access to the data. §5 summarizes the different data products produced by the various ground support organizations. §6 details the responsibilities of the MOC, the LAT IOC (LIOC), the GBM IOC (GIOC), the GSSC, and the HEASARC.

1.2 DEVELOPMENT, MAINTENANCE, AND MANAGEMENT RESPONSIBILITY

Developing, maintaining and managing this PDMP is a GLAST Project responsibility. The Project Scientist and the Science Working Group (SWG) are responsible for the development of this plan and assuring that its requirements are met.

1.3 CHANGE CONTROL

This PDMP is a GLAST Project-controlled document. Each year all plans and policies stated in the PDMP will be reviewed and updated as necessary by the SWG, the GLAST Users' Committee and the signatories to this document. An operational PDMP will be in place a year before launch; minor post-launch revisions are anticipated resulting from operational experience. Where possible, annual revisions will be released prior to the release of the NRAs that solicit proposals for the GLAST GI Program. Proposed changes will be submitted to the GLAST Project Scientist, who will coordinate the conduct of such reviews. Revisions of the PDMP will have the same review and approval process as the first version.

1.4 RELEVANT DOCUMENTS

Relevant documents, including NASA and GLAST Project documents, that provide detailed information in support of top-level information given in this PDMP, are listed below.

- GLAST Science Requirements Document, 433-SRD-001
- GLAST Mission Operations Concept Document, 433-OPS-0001
- GLAST Mission System Specification, 433-SPEC-0001
- GLAST Project Plan, 433-PLAN-0001 (Appendix—The Level I requirements)
- The GLAST Announcement of Opportunity for Flight Investigations (AO 99-OSS-03)
- "GLAST Large Area Telescope Flight Investigation: An Astro-Particle Physics Partnership Exploring the High-Energy Universe," P. Michelson, PI.
- "Gamma Ray Burst Monitor," C. Meegan, PI.
- GLAST SWG (Science Working Group) presentations, 05/25/00, 'GLAST Data Rights,' revised at the 2/03 SWG meeting.
- NASA/DOE Implementing Arrangement
- LAT IOC (Instrument Operations Center) Performance Specification, 433-RQMT-0003
- LAT Science Analysis Software Requirements Document, LAT-SS-20.0
- LAT IOC Performance Specification - Level II(B) Specification, LAT-SS-15.1
- LAT Science Analysis Software Management Plan, LAT-MD-360.1
- GBM IOC Requirements, GBM-REQ-1021.
- GBM Mission Operations and Data Analysis Software Requirements, GBM-REQ-xxxx.
- MOC (Mission Operations Center) System Specification
- MOC Functional Requirements Document, 433-RQMT-0001
- GLAST Science Support Center Functional Requirements Document, 433-RQMT-0002
- Science Data Products Interface Control Document

- Operations Data Products Interface Control Document
- GSSC-HEASARC Memorandum of Understanding
- Guidelines for Development of a Project Data Management Plan (PDMP), NASA Office of Space Science and Applications, March 1993
- Report of the GLAST Data Products Working Group

2 MISSION OVERVIEW

2.1 MISSION OBJECTIVES

The principal objective of the GLAST mission is to perform gamma-ray measurements over the entire celestial sphere, with sensitivity a factor of 30 or more greater than obtained by earlier space missions. GLAST will accomplish the next major step in high-energy gamma-ray astrophysics by providing major improvements in angular resolution, effective area, field-of-view (FOV), energy resolution and range, and time resolution.

GLAST's scientific objectives will be satisfied by two instruments. Covering the 20 MeV – 300 GeV energy range, the Large Area Telescope (LAT) will have a large collecting area, an imaging capability over a large FOV, and the time resolution sufficient to study transient phenomena. The LAT will also achieve sufficient background discrimination against the large fluxes of cosmic rays, earth albedo gamma rays, and trapped radiation that are encountered in orbit. The GLAST Burst Monitor (GBM) will detect and localize gamma-ray bursts (GRBs) in the classical 10 keV to 25 MeV energy band, and alert the LAT that a burst is in progress. GLAST will alter its observing plan to observe strong GRBs during and after the low-energy gamma-ray emission.

2.2 SCIENTIFIC OBJECTIVES

The high-energy gamma-ray universe is diverse and dynamic. Measuring the various characteristics of the many types of gamma-ray sources on timescales from milliseconds to years places severe demands on the GLAST mission. GLAST has the following specific scientific objectives:

1) Identify and study nature's high-energy particle accelerators through observations of active galactic nuclei, GRBs, pulsars, stellar-mass black holes, supernova remnants, Solar and stellar flares, and the diffuse galactic and extragalactic high-energy background.
2) Use these sources to probe important physical parameters of the Galaxy and the Universe that are not readily measured with other observations, such as the intensity and distribution of intergalactic infrared radiation fields, magnetic field strengths in cosmic particle accelerators, diffuse gamma-ray fluxes from the Milky Way and nearby galaxies, and the diffuse extragalactic gamma-ray background radiation.
3) Use high-energy gamma rays to search for a variety of as yet undetected and/or new phenomena, such as particle dark matter and evaporating black holes.

2.3 OBSERVATORY DESCRIPTION

The Observatory will consist of two instrument subsystems, the LAT and the GBM, combined with a spacecraft that will consist of eight orbital support subsystems: the Command And Data Handling (C&DH) subsystem; the Electrical Power and Distribution Subsystem (EPDS); the Communications (COMM) subsystem; the Attitude Control System (ACS); the Propulsion (PROP) subsystem; the Thermal Control Subsystem (TCS); the Structural/Mechanical (S&M) subsystem; and the Flight Software (FSW) subsystem. Figure 2-1 locates the LAT and GBM. The +Z axis is normal to the LAT. GLAST does not have any launch window constraints and is capable of pointing toward any direction on the sky. The spacecraft elements involved in data management are the C&DH subsystem, the solid-state recorder (SSR), Ku-band transmitter, S-band transmitter, and associated antennae.

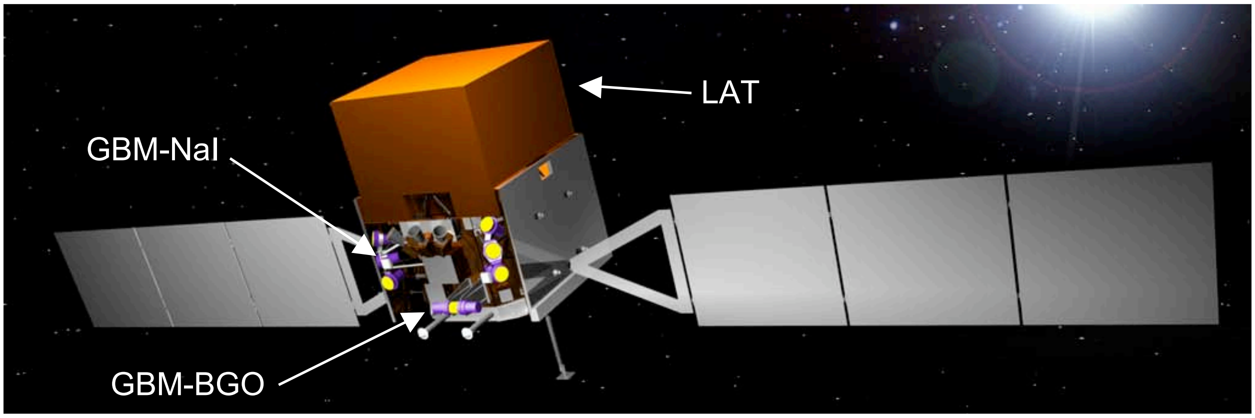

Figure 2-1: Schematic Diagram of GLAST Spacecraft and Science Instrument Locations

The C&DH subsystem will acquire science and engineering data. The system will accommodate a science data rate of 300 kbps (average) for the LAT and 25.5 kbps (maximum allocated) for the GBM, and will accommodate telemetry contacts that will downlink science and engineering data acquired at the average data rates. The GLAST C&DH subsystem will accommodate variable-length source packets for both science and engineering data. Typically, there will be ~4 eight to ten minute real time telemetry contacts per day. The GLAST Observatory will communicate principally with the ground through the Tracking and Data Relay Satellite System (TDRSS): a downlink of science and housekeeping data at Ku-band frequencies; a direct uplink of commands and software at S-band frequencies; and a S-band downlink for burst alerts and alarms. S-band uplink and downlink directly to ground stations will be possible as a backup to TDRSS.

2.4 MISSION TIMELINE

GLAST will be launched in September, 2006, from the Eastern Test Range (ETR) into an initial orbit of ~550 km altitude at a 28.5° inclination and an eccentricity <0.01. There are no mission constraints on the launch window. The mission design lifetime will be a minimum of 5 years, with a goal of 10 years.

After launch the mission will go through three phases: on-orbit initial checkout (Phase 0), a one year science verification period during which a full sky survey will be performed (Phase 1), and then at least four years of operations determined by the scientific goals and requirements of guest investigations (Phase 2). There will be one cycle of guest investigations during the verification and sky survey phase, and annual guest investigation cycles during the mission's third phase. Note that in this document "phases" refers to the periods of time with different operations, and "cycle" to the period of time (nominally one year) during which the guest investigations solicited by an NRA are carried out.

2.4.1 PHASE 0: ON-ORBIT CHECKOUT

On-orbit checkout is expected to take 30-60 days. The spacecraft subsystems will be evaluated and checked first. Subsequently, the instruments will be turned on, tested, and calibrated. The main observation modes will be checked out. Initially GLAST will point the LAT at bright targets such as the Crab nebula or Vela pulsar for approximately 2 to 3 weeks in the pointed observation mode. Then the observatory will be operated in the various observing modes (see §2.5) and the trigger modes of the instruments will be tested.

The spacecraft and instrument operations teams will be augmented for extended operations as necessary during this phase. The Flight Operations Team (FOT) will staff the MOC around the clock for the initial checkout and then reduce staffing to only a prime shift by the end of this phase.

2.4.2 PHASE 1: VALIDATION AND SKY SURVEY

As soon as it is declared operational, GLAST will carry out a validation and sky survey phase for one year. During this phase the performance of the science instruments will be fully characterized and validated, and the data processing pipelines will be refined based on operational experience. The spacecraft will operate primarily in a sky survey mode designed for relatively uniform sky coverage. The survey may be interrupted to follow 5-10 bright transients, typically for a few orbits. An NRA for Phase 1 of the GLAST GI Program will be released approximately 12 months prior to launch. The limited number of selected Phase 1 guest investigations must not interfere with the validation of the instruments or the all-sky survey.

2.4.3 PHASE 2: GUEST INVESTIGATOR (GI) OBSERVATIONS

During Phase 2 the mission timeline will be determined by the selected GI observations proposed in response to NRAs for the GLAST GI Program. Because of the LAT's wide FOV, survey mode is anticipated to be the baseline operational mode during this phase of the GLAST mission. However, since the observatory is designed to "point anywhere at any time," several observational modes will be available to GIs to support their scientific investigations.

2.5 OBSERVING MODES

The GLAST instruments will have very wide FOVs, and the observatory will be quite flexible in the direction in which it can point. An observational constraint will be to avoid pointing at or near the Earth to maximize the detection of astrophysical photons. Orientation requirements for the LAT cooling radiators and the observatory solar panels may impose engineering constraints, especially during slewing maneuvers. No science data will be taken when the observatory is in the South Atlantic Anomaly (SAA) since the instruments will lower the voltage on their photomultiplier tubes (PMTs). GLAST will operate in a number of observing modes.

Survey mode: This mode will predominate during most of the mission. In this mode the LAT will be pointed at or near the zenith (i.e., directly away from the Earth). As the spacecraft orbits the Earth, the zenith point will describe a great circle on the sky. Uniformity will be achieved by "rocking" the pointing perpendicular to the orbital motion. For example, every orbit the pointing may be moved from 30° on one side of the orbit to 30° on the other, resulting in a two orbit periodicity. The figure-of-merit to be optimized by a particular rocking profile is nominally uniformity of sky coverage, but may change as the mission progresses.

Inertial pointing mode: In this inertially-stabilized mode the LAT z-axis will be pointed directly at a target. This mode will be used when justified by the demands of the particular investigation. A pointing observation may be optimum for pulsar timing studies (to reduce the effect of variations in a pulsar's period) or for other studies where building up exposure over a short time will be useful. This mode will require careful coordination to keep the Earth out of the FOV. The LAT may observe a secondary target when the Earth occults the primary target.

Pointed-scan mode: In the pointed-scan mode the target is kept within the FOV whenever it is above the Earth's horizon. By allowing the target to drift within the FOV, the limb of the Earth can be kept out of the FOV, the exposure to secondary targets can be maximized, other secondary targets can be acquired more rapidly when the Earth occults the primary target, and the primary target can be reacquired more rapidly after an Earth occultation. The acceptable angle between the source and the LAT's normal (the spacecraft's z-axis) is less than 30°. Pointed-scan mode can provide more uniform sky coverage than the inertial pointing mode.

Special engineering modes will be implemented to generate diagnostic data on the instruments' performance. For example, for short periods of time the LAT can acquire and transmit unfiltered data (i.e., without the on-board cuts that eliminate most of the events that are not astrophysical gamma rays); the on-board cuts can be tested on the ground with unfiltered data. These engineering modes may occur during any of the observing modes.

Transitions between modes may be commanded from the ground or by the spacecraft. Commanded mode changes may be requested by the instrument teams, GIs or the Project Scientist. They will be implemented following appropriate review by the IOCs, the GSSC and the MOC. Based on data from the LAT or the GBM, the LAT can request autonomous repointing of the spacecraft and change the observing mode to monitor the location of a GRB (or other short timescale transient) in or near the LAT's FOV. After a pre-determined time the spacecraft will return to the mode of the interrupted observation.

Finally, the spacecraft can be placed into safe mode either autonomously or via ground command if anomalous behavior is detected that threatens the mission's safety.

2.6 GLAST'S GROUND OPERATIONS

A number of elements (organizations) are involved in GLAST's ground operations. The roles and responsibilities of these elements for managing GLAST's data are described in detail in §6. Figure 2-2 shows schematically the relation between these elements.

The MOC is the element that will interface to the spacecraft. The MOC will receive all the data from the spacecraft (through the ground network), monitor the performance of the spacecraft, distribute the relevant data to the other organizations, and transmit commands and revised flight software to the spacecraft. The MOC will be staffed by the FOT 8 hours a day, 5 days a week; in the event of a TOO or an anomaly a member of the FOT will be paged to come to the MOC when the MOC is not staffed.

Located at GSFC, the GSSC will distribute data, software products, and related information to the scientific community. The GLAST GI Program will be organized and administered by the GSSC. The GSSC will also plan the science observations and support science operations decisions such as TOO observations. The GSSC will maintain databases of various data products for use during the mission; these databases will become the mission archives in the HEASARC at the end of the mission.

The LAT and GBM instrument teams will establish IOCs for monitoring their respective instruments, processing the data from the instruments into a form useful for scientific analysis, and carrying out the teams' scientific investigations. The LAT IOC (LIOC) will be at Stanford University (SU), while the GBM IOC (GIOC) will be at National Space Science and Technology Center (NSSTC) located in Huntsville, Alabama. The IOCs may have internal structure that is not discussed here. The IOCs may support mirror data centers outside the United States associated with the instrument teams.

Telemetry from the observatory will reach the MOC through two pathways. The primary pathway is the Space Network (SN), which consists of the TDRSS satellites, the White Sands Complex (WSC) through which TDRSS downlinks and uplinks data and command, and the associated networks that deliver the data to the MOC. The secondary pathway, the Ground Network (GN), consists of ground stations through which the observatory downlinks and uplinks data and commands directly, and the associated networks.

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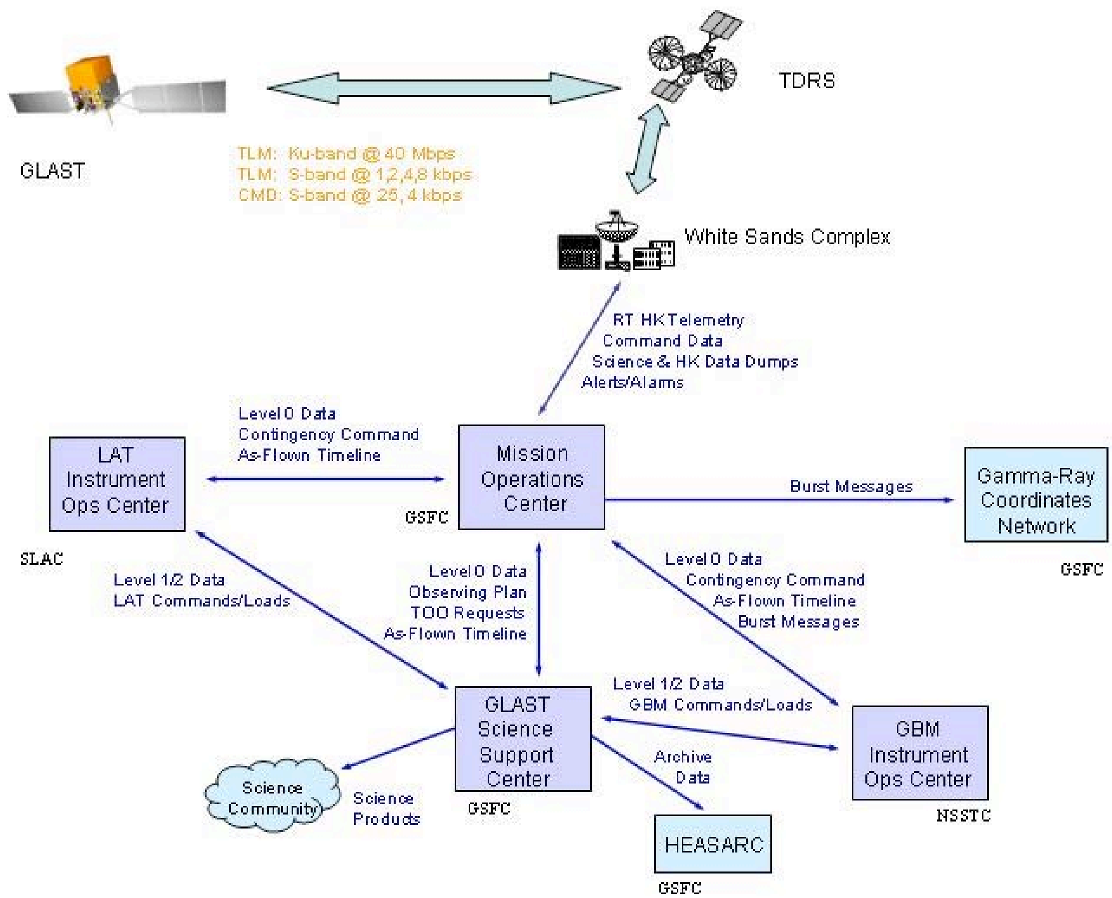

Figure 2-2: GLAST Ground Operations Overview. Only the elements involved in the data management during normal operations are shown.

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2.7 MISSION SUMMARY

Table 2-1: Mission Overview

Mission Summary	
Project Name	Gamma-ray Large Area Space Telescope (GLAST)
Orbit Description	≤28.5° inclination, initial ~550 km circular orbit, 94 minute period
Launch Date	September 2006
Launch Vehicle	Delta II 7920H-10C
Nominal Mission Duration	5 years
Mission Life Goal	10 years
Data Acquisition	
On-Board Data Storage Capacity	42 Gbits
Continuous Data Acquisition Rate	28 Gbits per day
On-Board storage saturation	
Attitude control accuracy	<2° (1σ)
Attitude determination accuracy	<10 arcsec (1σ)
Space to Ground Communications Data Rates	
Space Forward Average	250 bps S-band TDRSS MAF
Contact Frequency	ToO
Average	4 kbps S-band TDRSS SSAF
Contact Frequency	As required for large software loads
Space Return Average	40 Mbps Ku-band
Contact Frequency	~4 per day
Average	1 kbps S-band TDRSS MAR
Contact Frequency	1 per week
Average	4 kbps S-band TDRSS SSAR
Contact Frequency	As required for large memory dumps
Average	1 kbps S-band TDRSS DAS
Contact Frequency	On demand
Data Loss	<2%
Data Corruption	$<10^{-10}$

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3 Instrument Overviews

3.1 THE LARGE AREA TELESCOPE (LAT)

3.1.1 EXPERIMENTAL OBJECTIVES

The LAT's principal objective will be high sensitivity gamma-ray observations of celestial sources in the energy range from ~20 MeV to >300 GeV. The LAT will have a wide FOV (>2 sr), large effective area (>8,000 cm^2 maximum effective area at normal incidence at a few GeV), and excellent angular resolution (on-axis single photon 68% space containment angle: <0.15º for E>10 GeV and <3.5º for E=100 MeV). The LAT will provide good energy resolution ($\Delta E/E<10\%$ in the central part of the energy range) to enable spectral studies of high-energy sources. The actual values may be better than the required values given here.

The LAT will detect point sources that are more than 200 times fainter than the Crab nebula. For strong point sources, the position will be determined to about 0.5 arcminute. Spectra will be measurable over the entire energy range for the stronger sources.

The energy spectra of the Galactic plane diffuse emission will be measured with high accuracy and spatial variations will be resolved on a scale of about 0.5º. Features that subtend more than 0.25º will be identified as extended and not as point sources.

The diffuse radiation away from the Galactic plane will be separable into Galactic and extragalactic components. The improved point source sensitivity of the LAT relative to previous missions will allow the study of the spectral and spatial variation of the extragalactic component, leading to the determination of the unresolved point source contribution to the diffuse radiation measured by the *CGRO*'s Energetic Gamma-Ray Experiment Telescope (EGRET). The LAT is required to have a background of "false" (incorrectly identified cosmic rays) and non-celestial gamma rays (i.e., the residual background) <10% (with a design goal of <1%) of the high-latitude diffuse photon flux (as measured by EGRET) for E>100 MeV.

The large FOV and low dead time (<100 μs/event required, actual will most likely be much smaller) will allow the LAT to monitor the sky for high-energy transients, particularly GRBs. On-board data processing will allow near real-time notification to the ground of transients.

The GLAST LAT Collaboration includes scientists from Stanford University, including SLAC (PI: Prof. P. Michelson); GSFC; University of California at Santa Cruz; Naval Research Laboratory; University of Washington; Sonoma State University; Texas A&M University-Kingsville; Stockholm University and Royal Institute of Technology, Stockholm; Commissariat a l'Energie Atomique, Departement d'Astrophysique, Saclay, France; Institut National de Physique Nuclearie et de Physique des Particules, France; Instituto Nazionale di Fisica Nucleare, Italy; Agenzia Spaziale Italiana, Italy; Instituto di Fisica Cosmica, CNR; Hiroshima University; Institute of Space and Astronautical Science, Tokyo; Riken; and the Tokyo Institute of Technology. In addition, Affiliated Scientists are from 29 institutions world-wide.

3.1.2 LAT INSTRUMENTATION

Shown schematically in Figure 3-1, the LAT will consist of an array of 16 tracker (TKR) modules, 16 calorimeter (CAL) modules, and a segmented anticoincidence detector (ACD).

The TKR and CAL modules will be mounted to the instrument grid structure. Abstracted from the Science Requirements Document (433-SRD-001), Table 3-1 summarizes the required capabilities of the LAT instrument.

Each TKR module will consist of 18 XY tracker planes. Each XY plane will have an array of silicon-strip tracking detectors (SSDs) for charged particle detection. The first 12 planes will have 0.035 radiation length[1] thick tungsten plates in front of the SSDs, the next 4 planes will have 0.18 radiation length thick tungsten plates, and the last 2 planes, immediately in front of the CAL, will not have tungsten plates. The SSDs in each plane will actually consist of two planes of strips, one running in the x and the other in the y direction, thereby localizing the passage of a charged particle. Gamma rays incident from within the LAT's FOV will preferentially convert into an electron-positron pair in one of the TKR's tungsten plates. The initial directions of the electron and positron will be determined from their tracks recorded by the SSD planes following the point of conversion. Cosmic rays will also interact within the TKR modules. Reconstruction of the interactions from the tracks will identify the type of particle as well as its energy and incident direction.

Each CAL module will consist of 8 planes of 12 CsI(TI) crystal logs each. The logs will be read out by PIN diodes at both ends. The CAL's segmentation and read-out will provide precise three-dimensional localization of the particle shower in the CAL. At normal incidence the CAL's depth will be 8.5 radiation lengths.

The ACD will be composed of plastic scintillator segmented into tiles, supplemented with fiber ribbons, and read out by waveshifting fibers connected to PMTs.

The LAT's Data Acquisition System (DAQ) will perform preliminary cuts on events within the LAT, to reduce the rate of background events that will be telemetered to the ground. The DAQ will process the captured event data into a data stream with an average bit rate of 300 kbps for the LAT. The DAQ will also perform: command, control, and instrument monitoring; housekeeping; and power switching.

3.1.3 DATA ACQUISITION

The astrophysical photons of primary interest will be a tiny fraction of the particles that will penetrate into the LAT's TKR. The on-board analysis cuts that the LAT will perform will reduce the up to 10 kHz of events that trigger the TKR to ~30 Hz of events that will be sent to the ground for further analysis; of these ~30 Hz only ~2 Hz are astrophysical photons. The data for an event that passes the on-board analysis cuts will be stored in a packet with a time stamp and details of the signals from the various LAT components. Because the number of signals for a given event may vary, the data packets will have variable length. These data packets describing each event are the LAT's primary data product. The LAT will transfer these packets to the spacecraft's SSR for eventual transmission to the ground.

[1] A radiation length is defined as the length in a specific material in which an energetic electron will lose $1-e^{-1}$ of its energy by bremsstrahlung.

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Table 3-1: LAT Description and Required Capabilities	
1. LAT Detectors	
Tracker (TKR)	Single-sided silicon-strip detectors, in 16 modules, each with 18 XY tracking planes
Calorimeter (CAL)	Hodoscopic configuration of CsI(Tl) crystals, in 16 modules, each with 8 layers of 12 CsI logs
Anticoincidence Detector (ACD)	Array of plastic scintillator tiles, read out with waveshifting fibers coupled to photomultiplier tubes
2. LAT Capabilities	
Energy Range	<20 MeV to >300 GeV
Energy Resolution	<10% on axis, 100 MeV—10 GeV
Effective Area	>8,000 cm^2 maximum effective area at normal incidence; includes inefficiencies to achieve required background rejection
Single Photon Angular Resolution	<0.15 degrees, on-axis, 68% space angle containment radius for E > 10 GeV <3.5 degrees, on-axis, 68% space angle containment radius for E = 100 MeV
Field of View	> 2 sr
Source Location Determination	< 0.5 arcmin for high-latitude source
Point Source Sensitivity	$< 6 \times 10^{-9}$ ph cm^{-2} s^{-1} for E > 100 MeV, 5σ detection after 1 year sky survey
Time Accuracy	< 10 microseconds, relative to spacecraft time
Background Rejection (after analysis)	< 10% residual contamination of high latitude diffuse sample in any decade of energy for E > 100 MeV.
Dead Time	< 100 microseconds per event
3. GLAST-LAT Interface	
Mass	3000 kg (allocation)
Size	1.5 m x 1.75 m x 1.0 m
Power	650 W (allocation)
Average Science Data Rate	300 kbps

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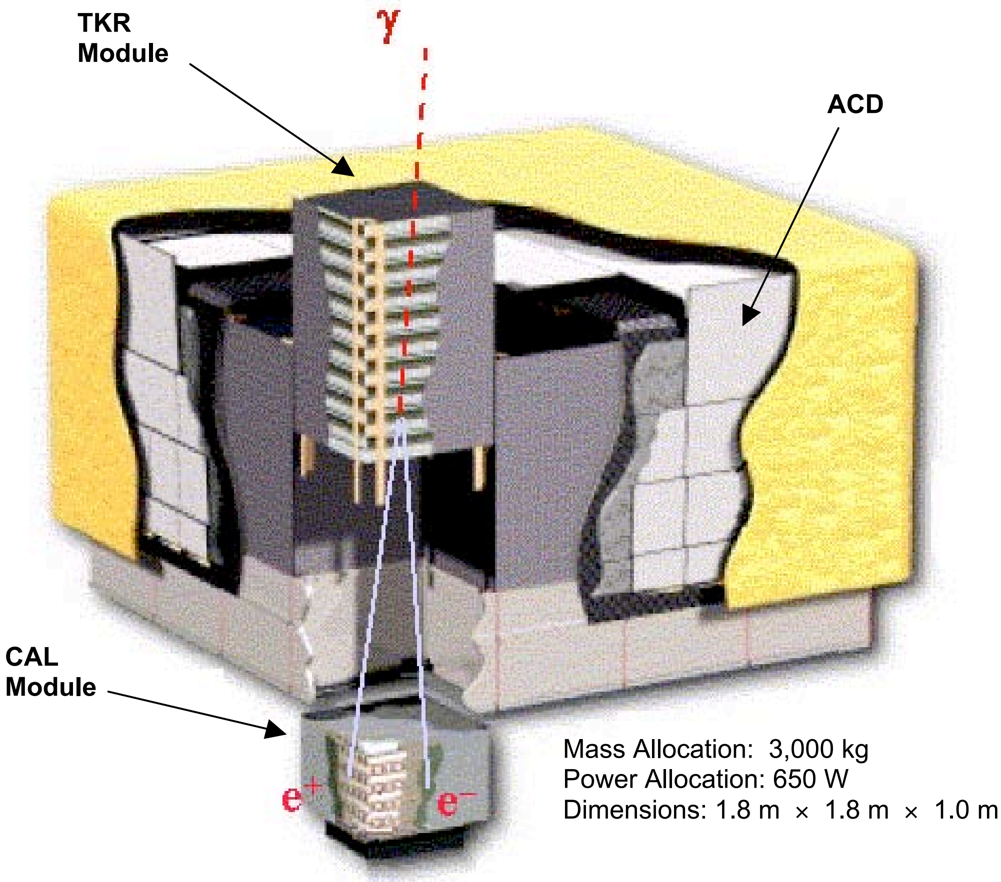

Figure 3-1: LAT Instrument Schematic

3.2 THE GLAST BURST MONITOR (GBM)

3.2.1 EXPERIMENTAL OBJECTIVES

The GBM will provide simultaneous low-energy spectral and temporal measurements for all GRBs within the LAT FOV. The combined effective energy range will span more than 7 energy decades from 10 keV to 300 GeV. The GBM extends the energy coverage from below the typical GRB spectral break at ~100 keV to above the LAT's low-energy cutoff for inter-instrument calibration. Furthermore, the GBM's sensitivity and FOV will be commensurate with the LAT's to ensure that many bursts will have simultaneous low-energy and high-energy measurements with similar statistical significance. The GBM will also assist the LAT detect and localize GRBs rapidly by providing prompt notification of a burst trigger. Finally, the GBM will provide coarse GRB locations over a wide FOV that can be used to repoint the LAT at particularly interesting bursts outside the LAT FOV for gamma-ray afterglow observations, or to notify external follow-up observers.

Table 3-2 lists the GBM's requirements and goals, as well as the driving scientific measurement.

Table 3-2: GBM Scientific Performance Requirements

Parameter	Requirement	Goal	Main Driver
Low Energy Limit	<10 keV	<5 keV	Characterize spectra below break
High Energy Limit	>25 MeV	>30 MeV	Overlap LAT energy range
Energy Resolution[a]	<10%	<7%	Continuum spectroscopy
Field of View[b]	>8 sr	>10 sr	Match or exceed LAT FOV
Time Accuracy[c]	<10 μs	<2 μs	Measure rapid variability
Average Dead Time	<10 μs/count	<3 μs/count	Measure intense pulses
Burst Sensitivity[d]	<0.5 cm^{-2} s^{-1}	<0.3 cm^{-2} s^{-1}	Consistent with LAT GRB sensitivity
Burst Alert Locations[e]	—	<15°	Sufficient to repoint LAT
Burst Alert Time Delay[f]	<2 s	<1 s	Less than typical GRB duration

[a] FWHM, 0.1–1 MeV
[b] Co-aligned with LAT FOV
[c] Relative to spacecraft time
[d] Peak flux for 5σ detection in ph cm^{-2} s^{-1} (50–300 keV)
[e] 1σ systematic error radius
[f] Time from burst trigger to spacecraft notification (used to notify ground or LAT)

Using detection criteria similar to those of *CGRO*'s Burst And Transient Source Experiment (BATSE), the predicted GBM burst detection rate is in the range of 150–225 per year, depending on GLAST's pointing schedule (i.e., the fraction of time the Earth blocks the GBM FOV). In practice, the GBM will detect GRBs at a higher rate through a more flexible trigger algorithm that will improve background estimates, and that will use several different energy ranges and timescales.

The average GBM statistical location uncertainty for all detected GRBs is estimated to be ~15° (1σ radius), improving to ~9° (~1.5°) for the brightest 40% (5%) of the bursts. The systematic location error is estimated to be ~5-10° for on-board processing and ~1–2° for final ground processed data.

For bright GRBs, the combination of GBM and LAT measurements will constrain the time-averaged burst spectrum over more than five energy decades with typical statistical uncertainties for the spectral parameters of less than 1% (~2-10% for GRBs dimmer by a factor of ten). In addition to measuring low-energy spectra below the LAT threshold, the GBM will significantly improve the constraints on high-energy spectral behavior compared to those of the LAT alone. The combination of GBM and LAT data will therefore provide a powerful tool to study GRB spectra and their underlying physics.

The GBM collaboration includes scientists from the Marshall Space Flight Center (PI: Dr. C. A. Meegan), the Max Planck Institute for Extraterrestrial Physics (MPE; Co-PI: Dr. G. Lichti), the University of Alabama in Huntsville, the Universities Space Research Association (USRA), and Los Alamos National Laboratory. The Marshall, University of Alabama, and USRA scientists are housed at the NSSTC.

3.2.2 GBM INSTRUMENTATION

To achieve the required GBM performance, the design and technology borrow heavily from previous GRB instruments, particularly from BATSE. Like BATSE, the GBM will use two types of cylindrical crystal scintillation detectors, whose light will be read out by PMTs.

An array of 12 sodium iodide (NaI) detectors (0.5 in. thick, 5 in. diameter) will cover the lower end of the energy range up to ~1 MeV. The GBM will trigger off of the rates in the NaI detectors. Each NaI detector will consist of the crystal, an aluminum housing, a thin beryllium entrance window on one face, and a 5 in. diameter PMT assembly (including a pre-amplifier) on the other. These detectors will be distributed around the GLAST spacecraft (see Figure 3-2) with different orientations to provide the required sensitivity and FOV. The cosine-like angular response of the thin NaI detectors will be used to localize burst sources by comparing rates from detectors with different viewing angles. To cover higher energies, the GBM will also include two 5 in. thick, 5 in. diameter bismuth germanate (BGO) detectors. The combination of the BGO detectors' high-density (7.1 g cm^{-3}) and large effective Z (~63) will result in good stopping power up to the low end of the LAT energy range at ~20 MeV. The BGO detectors will be placed on opposite sides of the GLAST spacecraft to provide high-energy spectral capability over approximately the same FOV as the NaI detectors. For redundancy, each BGO detector will have two PMTs located at opposite ends of the crystal.

The signals from all 14 GBM detectors will be collected by a central Data Processing Unit (DPU). This unit will digitize and time-tag the detectors' pulse height signals, package the resulting data into several different types for transmission to the ground (via the GLAST spacecraft), and perform various data processing tasks such as autonomous burst triggering. In addition, the DPU will be the sole means of controlling and monitoring the instrument. For example, the DPU will control the PMTs' power supply to maintain their gain.

3.2.3 DATA ACQUISITION

There will be three basic types of science data: (1) continuous data consisting of the count rates from each detector with various (selectable) energy and time integration bins; (2) trigger data containing lists of individually time-tagged pulse heights from selected detectors for periods before and after each on-board trigger; and (3) Alert Telemetry containing computed data from a burst trigger, such as intensity, location, and classification. The Alert Telemetry will be transmitted by the spacecraft to the MOC through TDRSS in less than 5 s (with 1 s allotted for the spacecraft to generate the alert, and 1 s for the MOC to prepare the GCN message, the total time from burst to GCN Notice will be less than 7 s). Alerts will also be sent to the LAT and to the spacecraft to aid in LAT GRB detection and repointing decisions. The remaining data types will be transmitted via the scheduled Ku-band contacts with a typical latency of <12 hours. The GBM is expected to produce an average of 1.4 Gbits/day, with a minimum of 1.2 Gbits/day and a maximum allocated rate of 2.2 Gbits/day.

The main GBM operating modes, continuous and burst trigger, correspond to the type of data being collected and transmitted. Additional modes will be used in response to anomalies.

1. **Continuous mode** will be the normal operating mode of the instrument. All instrument voltages will be on and the continuous data types will be acquired and transmitted. Pre-trigger event data will be acquired but not transmitted.
2. **Burst trigger mode** will be enabled upon command from the autonomous burst trigger software, or by direct command from the spacecraft. In addition to the continuous data types, the trigger data types will also be acquired and transmitted. Instrument voltages will

be unaffected. The instrument will return autonomously to continuous mode under software control.

3. **Diagnostic mode** will be enabled and disabled upon direct command from the spacecraft. Some instrument voltages may be turned off or adjusted, and mode-specific data types may be acquired and transmitted in addition to some combination of continuous and trigger data types. This mode will be used infrequently in response to anomalies, and possibly during the initial on-orbit checkout.

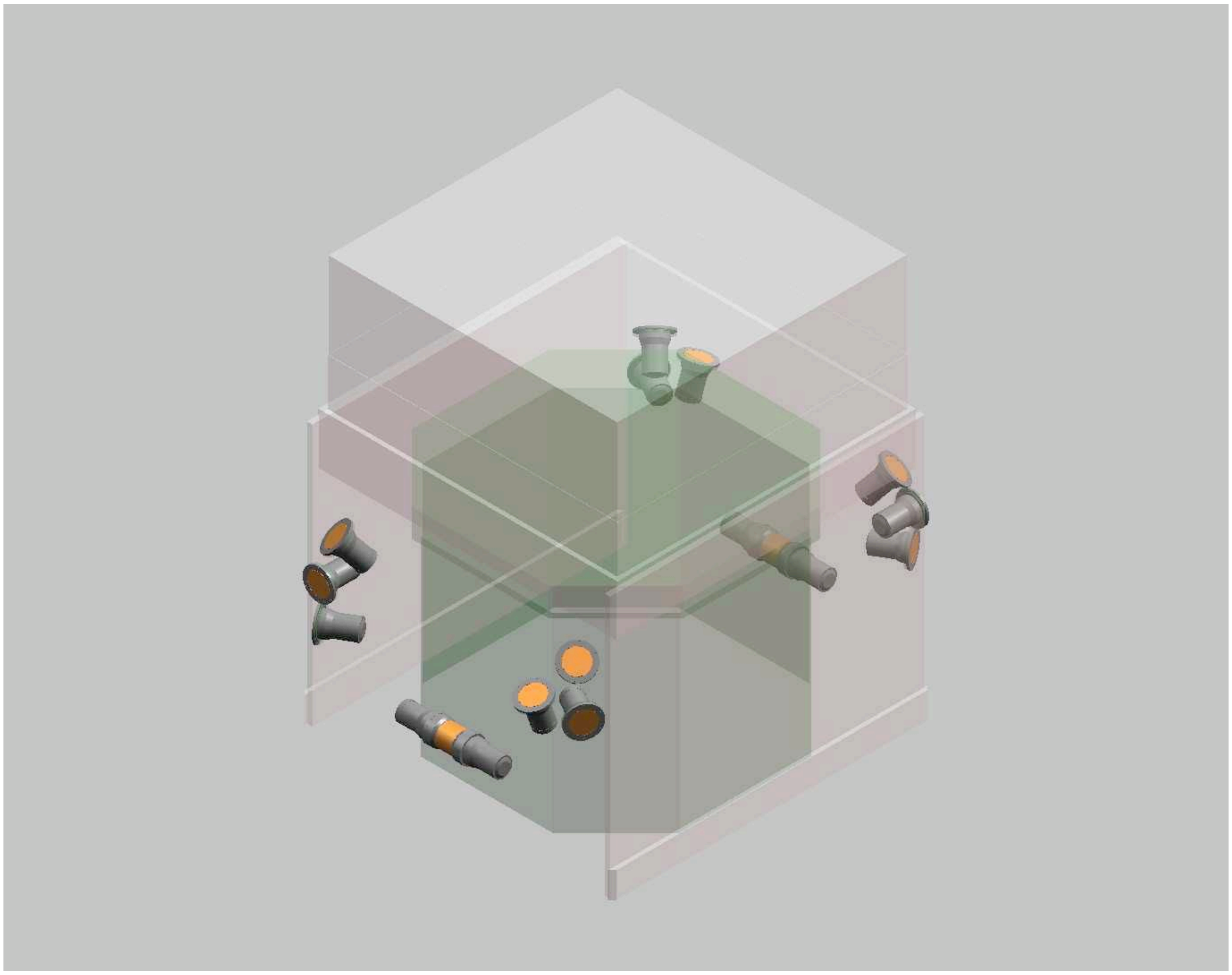

Figure 3-2: Placement of GBM Detectors on GLAST

4. **Safe mode** will be enabled and disabled upon direct command from the spacecraft, or may be enabled autonomously by the GBM.
5. **SAA** mode will be enabled and disabled upon direct (stored) command from the spacecraft. Detector high voltages will be turned off while the spacecraft is in the SAA. If the mode is entered from continuous mode, only engineering data will be acquired and transmitted. If the mode is entered from burst trigger mode, pre-trigger event data may also be transmitted.

4 PROJECT DATA FLOW

4.1 DATA DESCRIPTION

4.1.1 RAW DATA

Raw data are provided by the spacecraft telemetry to the ground. They may contain duplicate data packets, data packets out of time order, damaged packets, etc. All raw data will be retained at WSC (the SN's ground station) for seven days in case it becomes necessary to retransmit it for any reason. Raw data will be archived at the MOC for the duration of the mission.

4.1.2 LEVEL 0 DATA

Level 0 data will have undergone minimal processing. No information will be lost, but duplicate data packets will be removed, quality checks will be made, and the data packets will be time-ordered. The raw data will be decompressed (if necessary) and separated into spacecraft and instrument packets. Level 0 processing converts the raw data into the Level 0 data. All Level 0 data will be archived at the GSSC while the instrument-specific Level 0 data will be archived at the IOCs. Level 0 processing will be done at the MOC.

4.1.3 LEVEL 1 DATA

Level 1 data result from "automatic" pipeline processing of Level 0 data. The resulting Level 1 data are generally the starting point for scientific analyses. Level 1 processing of LAT and GBM data will be performed at the LIOC and the GIOC, respectively.

In LAT Level 1 processing, the Level 0 data describing the interactions within the LAT will be analyzed to identify and characterize the interacting particle (e.g., photons, electrons, protons, etc.). Thus tracks will be fitted to the hits in the TKR and CAL, the particle trajectories and energies will be calculated, and the event will be classified. The Level 1 data for an event will include at least the event arrival time, apparent energy and apparent origin on the sky. Other LAT Level 1 data will include histories of the instrument live time and pointing.

GBM Level 1 processing will primarily re-format and reorganize the data. The gains of each detector will be calibrated by monitoring the pulse-height channels of one or more background spectral lines. These gains will then be used to convert the raw detector pulse-height channels to an apparent energy. Level 1 continuous data products will include all time-resolved spectra collected in continuous mode, together with the calibration parameters and other ancillary information such as spacecraft ephemerides, instrument live time, etc. The rough trigger classification determined on-board will be reviewed by GIOC personnel and further processing will be performed as appropriate, such as improved GRB localization, and standard measurements of fluence, peak flux, and duration. Level 1 triggered data products will include all burst mode data types as well as continuous mode data collected within a specified time interval (nominally 4000 s) before and after the trigger time, together with the calibration parameters, ancillary information as above, and the associated parameters determined from analysis.

4.1.4 LEVEL 2 DATA

Level 2 data will result from routine scientific analysis, often using the science analysis software developed for more focused studies, e.g., by GIs and the instrument teams. For LAT observations these data may include: exploratory science analyses; quick-look analyses to detect transient sources and to support operations planning; standard analysis of transient sources; refined analyses of on-board GRB and AGN transient alerts; and LAT sky maps accumulated over a variety of time intervals. For GBM observations Level 2 data might include the uniform fitting of GRB spectra with standard spectral models.

4.1.5 LEVEL 3 DATA

Level 3 data will consist of catalogs and compendia of Level 2 data. The LAT team will produce a catalog of gamma-ray sources, including (but not limited to) flux histories and tentative source identifications. The first LAT catalog will be based on the first-year sky-survey data; updates are to be released following the 2^{nd} and 5^{th} years of operation, and the end of the mission. The LAT team will also produce an all-sky map for the verification and sky-survey phase. The GBM team will release catalogs of GBM burst energy spectra. Both instrument teams will maintain catalogs of transient events.

4.1.6 ANCILLARY DATA

The LAT team will produce, update and make public the diffuse Galactic interstellar and extragalactic emission models used for the analysis resulting in the LAT source catalogs. As a spatially varying background underlying point sources, the diffuse emission must be known to detect point sources. The diffuse Galactic emission is intrinsically interesting because it results from the interaction of cosmic rays with gas and photons in our galaxy.

4.1.7 DATABASES

The GSSC will maintain databases of Level 0, 1, 2 and 3 data as well as other data (e.g., housekeeping) to support scientific analysis during the mission and will provide these databases to the HEASARC by the end of the mission where they will constitute the mission archives. In addition, the instrument teams will maintain databases for their own use. As appropriate, these databases will be searchable by different categories, e.g., event energy or time. The databases will include calibration data, instrument response functions, event data, timeline data, exposure history, and source catalogs. For the LAT, the Level 1 processed event database will consist of the parameters determined from the analysis of all triggered events identified as gamma rays or cosmic rays, including reconstructed track and energy information, identification of events by particle type (cosmic rays, photons), event time, etc.

4.2 END-TO-END DATA FLOW

4.2.1 DATA FLOW BETWEEN THE OBSERVATORY AND THE MOC

GLAST's science instruments will transfer data continuously to the spacecraft (averages of 300 kbps for the LAT and 16.7 kbps for the GBM), which will then store the science and housekeeping data in the SSR. Science data from each instrument and required ancillary data from the spacecraft will be loaded into telemetry packets on-board the observatory. All data packets will have unique identifiers for the source of the data (e.g., LAT, GBM, spacecraft). Time tags will be inserted on-board at the time of data acquisition. The telemetry will be formatted following the recommendations of the Consultative Committee for Space Data System (CCSDS).

The observatory will communicate with the MOC primarily through the Space Network (SN). The MOC will schedule contacts ~4 times per day. During these scheduled contacts science and housekeeping data will be downlinked on the Ku-band at 40 Mbps, and commands will be uplinked on the S-band at 4 kbps (other data rates may be possible). The 36 hour capacity of the SSR onboard the spacecraft permits the loss of a number of contacts without the loss of science data. In some spacecraft orientations the observatory cannot communicate with the TDRSS satellites via Ku band; however, given the SSR's large storage capacity and the flexibility of the SN system, a scheduled telemetry contact need not disrupt an observatory pointing. The MOC will monitor the downlink data quality in real-time using frame status and accounting information from WSC. If the data quality is unacceptable, the MOC may initiate the retransmission from the spacecraft of some or all of the data. If time allows, this will be done during the contact; if not, the MOC may schedule another contact. Similarly, after a contact the MOC will verify that the data have been received, distributed and stored correctly. If data are lost or below the quality threshold, a retransmission will be requested within 7 days first from WSC, and if necessary from the spacecraft. Therefore, WSC will store the received data for at least 7 days.

Table 4-1: Telemetry Parameters

Parameter	Values
Data Rates	
Space Forward Average	250 bps S-band TDRSS MAF
Contact Frequency	ToO
Average	4 kbps S-band TDRSS SSAF
Contact Frequency	As required for large software loads
Space Return Average	40 Mbps Ku-band
Contact Frequency	~4 per day
Average	1 kbps S-band TDRSS MAR
Contact Frequency	1 per week
Average	4 kbps S-band TDRSS SSAR
Contact Frequency	As required for large memory dumps
Average	1 kbps S-band TDRSS DAS
Contact Frequency	On demand
Data Loss	<2%
Data Corruption	$<10^{-10}$

On-demand S-band uplinks and downlinks will also supported. Burst Telemetry and spacecraft alarms will be downlinked through TDRSS's Demand Access Service (DAS) at 1 kbps. Burst Telemetry consists of a Burst Alert, informing the ground that either the GBM or the LAT has triggered on a burst, and additional spectral and temporal information about the burst. The MOC will receive the Burst Alert within 5 s after the alert leaves the observatory. If a scheduled Ku-band contact is in progress, the Burst Telemetry or spacecraft alarms will be downlinked over the Ku-band. Similarly, high priority commands (e.g., implementing TOOS or responding to an observatory crisis) may be uplinked at 250 bps (a higher rate may be feasible).

Scheduled S-band contacts with the GN may be used during observatory checkout and for contingencies. The spacecraft will be capable of downlinking real-time housekeeping at 2.5 Mbps, and uplinking commands at 2kbps. During normal operations the GN link will be exercised occasionally to insure its operational proficiency.

4.2.2 COMMANDING

The MOC will uplink non-time critical command loads through S-band uplink during the scheduled contacts and time critical command loads as needed. There will be three classes of commands: real-time commands that are executed immediately upon arrival at the spacecraft; Absolute Time Commands (ATCs) that are uplinked, stored in two spacecraft buffers and executed at specific absolute times; and Relative Time Sequence (RTS) tables that are stored in the spacecraft's memory and are invoked by the flight software, a real-time command or an ATC. For example, an ATC may invoke an RTS at a specific time while the spacecraft, and the RTS may then change all the gain settings of the GBM. A load of ATCs is called an Absolute Time Sequence (ATS) table. Real-time commanding will be used during the observatory checkout, while ATS commanding will predominate during normal operations.

Each command sent to the observatory includes a tag identifying the intended recipient: the spacecraft or one of the instruments. The instruments execute commands when they arrive; the instruments do not have a command buffer.

The MOC will maintain the Project Database (PDB) that will translate the human-intelligible command names into the bit patterns the CPUs on board the spacecraft will understand. In addition to commands, the ground system will use PROCs, procedures with parameters that are sent from an IOC through the GSSC to the MOC where the PROCs are expanded into a series of commands. PROCs may incorporate logic and telemetry verifications along with the commands to be issued.

The IOCs generate commands and flight software updates for their instruments, which are sent to the MOC through the GSSC. The GSSC evaluates the commands or flight software updates for their impact on the science timeline; if the impact is unacceptable, the GSSC may ask the IOC to resubmit the command load at a different time. If the command load is acceptable, the GSSC passes it on to the MOC. The GSSC will pass a command immediately to the MOC if an IOC marks it as very high priority (e.g., if the safety of the instrument is an issue). The MOC will produce, and the GSSC archive, an as-flown timeline.

During normal operations the MOC will construct and uplink the observatory timeline once a week by merging the science timeline from the GSSC, instrument commands that have been generated by the relevant IOC and approved by the GSSC, and spacecraft commands. Should the science timeline be revised as a result of TOOs or autonomous repointings, a new observatory timeline will be uplinked. While non-critical commands can be uplinked at any time, implementing commands through the weekly observatory timeline will be preferred.

4.2.3 PROCESSING BY THE MOC

The MOC will perform Level 0 processing on the raw data it will receive from the Ku-band contacts. Level 0 processing will correct transmission artifacts such as duplicate data packets and packets out of time order, and will annotate the data quality. The MOC then will send all the Level 0 data to the GSSC for archiving. The MOC will transmit the LAT science and engineering data to the LIOC and the GBM science and engineering data to the GIOC.

The GIOC will provide the MOC with the Burst Alert Processor (BAP), which will be a computer residing in the MOC; because of its proximity to the MOC, the GSSC will maintain the BAP on behalf of the GIOC. The MOC will pass the Burst Telemetry downlinked from the spacecraft through the TDRSS DAS (or the Ku-band downlink if the burst occurs during a scheduled contact) to the BAP. The BAP will format the burst alert (the burst position calculated by either the GBM or the LAT) and pass it to the Gamma-ray burst Coordinates Network (GCN) within 1 s of the alert's arrival at the MOC. The GCN will then disseminate the burst location as a GCN Notice to all interested observatories by internet socket, e-mail or pager. Taking advantage of greater CPU speed and memory, the BAP will calculate an improved burst location using the GBM Burst Telemetry, and send out the improved position as a GCN Notice. The LIOC may provide software to analyze LAT data sent down in the Burst Telemetry. The MOC will also send the GIOC the Burst Telemetry for further analysis with human intervention, if a better location results, the GIOC will send out another GCN Notice. Finally, each IOC may further refine the burst position using the full data downlinked through a scheduled Ku-band contact and report the resulting positions through further GCN Notices. The IOCs may also issue GCN Circulars describing additional burst information such as the fluence, duration, and spectral hardness. The GSSC will receive GLAST-related Notices and Circulars from the GCN (and not from the BAP or the IOCs) and post them on the GSSC website.

When the Project Scientist or his/her designee authorizes a TOO, the GSSC will send to the MOC within 2 hours a TOO order defining the TOO, and will notify the IOCs of the TOO. The MOC will construct the commands, schedule a forward telemetry service, transmit the commands to the spacecraft, verify that the commands have been executed, and notify the GSSC of whether the TOO was implemented. The MOC has 4 hours from the receipt of the TOO order from GSSC until the commands are sent to TDRSS; TDRSS has a further _ hour to transmit the commands to the spacecraft. If the MOC is not staffed when the TOO order is issued, a member of the FOT will come in to the MOC to implement the TOO order.

4.2.4 PROCESSING BY THE GSSC

The GSSC will receive all the Level 0 data from the MOC for archiving. The GSSC will receive Level 1 processed data from the IOCs. The GSSC's Level 1 database will be the source of data for the astronomical community, and maintained by the HEASARC, will be the final archive for these data after the mission ends. In this document "database" refers to collections of data maintained by the GSSC while "archive" refers to data maintained by the HEASARC. The GSSC will have backup Level 1 processing pipelines that mirror the production pipelines at the IOCs; the GSSC's backup pipelines will be activated in an emergency with the concurrence and assistance of the instrument teams.

The GSSC will also undertake certain Level 2 processing of LAT data to keep the astronomical community informed of the progress and results of the mission, and to assist GIs in planning GLAST-related research. Such processing may include maps of counts and exposure for the entire sky and for selected regions (e.g., the Galactic center or the region about 3C273). The GSSC will also monitor selected sources of general astrophysical interest. The Level 2 data will be available on the GSSC website and upon request.

During Phase 2 of the mission the GSSC will be the primary source of data for the GIs and the general astronomical community. During Phase 2 the Level 1 data will be accessible from the GSSC's databases within 24 hours after their arrival at the GSSC. After the observations necessary for a guest investigation have been performed, the investigator will create FITS files of the observation by extracting the data from the science databases (see the discussion below). The investigator will then transfer the FITS files back to his/her computer; the analysis software will be available through the GSSC's website.

In Phase 2 the GSSC will construct science timelines based on the guest investigations that have been selected from proposals submitted in response to NRAs. The science timeline will contain the direction and duration of pointed observations, as well as the commands the IOCs would like executed. The timeline will be conveyed to the MOC for implementation. In general, timelines will be produced weekly, but if the timeline must be changed (e.g., as a result of a TOO or an autonomous repoint in response to a burst), the GSSC will update the timeline.

In response to a transient event identified in another waveband or a newly discovered phenomenon demanding an immediate observation, the GLAST Project Scientist (or his/her designee) may declare a TOO observation based on guidelines established by the SWG. The GSSC will provide information to the project scientist supporting his/her decision-making, and will then transmit the order defining the TOO to the MOC.

The IOCs will periodically request that one of the GLAST instruments be operated in an engineering mode to collect diagnostics on the instrument's performance. The Project Scientist (or his/her designee) will approve such requests, and the GSSC will schedule the engineering mode operation. Optimally, the schedule for engineering mode operation will be developed at the beginning of each yearly cycle. Similarly, the IOCs will update their instruments' flight software over the course of the mission; the Project Scientist (or his/her designee) should be notified of updates that affect the scientific performance of the instruments or a GI's data. The GSSC will schedule the uplinks.

Finally, the GSSC will be responsible for producing and maintaining databases of the data products it will receive from the IOCs or it will produce itself (see §5). These GSSC databases will be used during the mission, and will become the archives maintained by the HEASARC afterwards. They will be constructed to conform to the standards of the HEASARC (§6.5.2.1), and will be created and maintained within the HEASARC (§6.5). For operational purposes the GSSC may distribute some of its databases over a multi-processor system during the mission, but will provide the HEASARC with a mutually agreed upon archival form by the end of the mission.

4.2.5 PROCESSING BY THE LIOC

The LIOC will receive LAT data from the MOC. During Phase 2 the LIOC will complete the Level 1 processing within 24 hours of receipt of the data. The resulting Level 1 data will be provided to the GSSC for dissemination within the astronomical community, and will be used by the LAT team for its investigations. The LIOC will provide data to mirror sites maintained by LAT instrument team collaborators.

During the mission the LAT team will occasionally operate the LAT in an engineering mode. The request for such a mode operation will be submitted to the GSSC; with the approval of the Project Scientist (or his/her designee), the GSSC will schedule the engineering mode operation. Similarly, the LAT team will periodically update the flight software. The revisions will be sent from the LIOC through the GSSC to the MOC to be uploaded to the spacecraft.

The LAT team will be responsible for maintaining a model of the Galactic interstellar and extragalactic diffuse emission, which are the background against which point sources are detected and analyzed (this emission is of course intrinsically interesting). Periodically the LIOC will send the GSSC an updated model.

4.2.6 PROCESSING BY THE GIOC

The GIOC's data management will be analogous to the LIOC's: it will complete Level 1 processing within 24 hours after receiving the GBM data from the MOC. The resulting Level 1 data will be provided to the GSSC for dissemination within the astronomical community, and will be used by the GBM team for its own investigations. Requests for engineering mode operations and revisions to the flight software will be submitted through the GSSC. The GIOC will also supply data to mirror data centers maintained by the GBM instrument team collaborators.

4.2.7 ARCHIVING

The GSSC will load all the data products provided by the other ground system elements (see §5) into databases that will conform to the standards of the HEASARC (§6.5.2.1). During the mission these databases will be used for GLAST research by the Project, the instrument teams and the scientific community. The databases will be on GSSC-provided computer disks mounted on servers that are part of the HEASARC system. When the GLAST GSSC is disbanded after the end of the GLAST mission, the databases will remain as part of the HEASARC archives. The GSSC's databases will in general conform to HEASARC standards, both in architecture and format. Specifically, the data will be in FITS files with metadata describing the data (and pointing to the FITS files) in a non-proprietary format (e.g., tables accessible to users through a web interface). Note that the HEASARC refers to the FITS data files as "archives" and to the metadata as "databases." In a few cases the GSSC may maintain a non-archival architecture for internal operational use. For example, the GSSC may create "optimized databases" which distribute HEASARC-format data files over multiple nodes for access speed; the access software will be able to read the data from one or multiple nodes. In all cases, the GSSC will provide databases acceptable for the HEASARC archives without conversion by the end of the mission, as described in the GSSC-HEASARC MOU. Similarly, the integration of the GSSC's access software with the HEASARC's will be described in the GSSC-HEASARC MOU. Even before the end of the mission the HEASARC's software may access the GLAST databases. The data products extracted from the GSSC databases will always conform to HEASARC standards.

The GLAST Project will retain Level 0 data during and after the mission (see §5); the MOC will preserve the raw telemetry during the mission. Archived GLAST data sets will be discarded only after review by the GSSC, the SWG and the GLAST Users' Committee.

4.3 DATA ACCESSIBILITY

4.3.1 GENERAL PRINCIPLES

The overarching principle behind the GLAST data release policy is optimizing the scientific return from the data. This will be achieved by the rapid release of the GLAST data and the discoveries resulting from these data.

Phases 0 and 1 constitute the “restricted access period.” During this period the instrument teams will use the Level 1 data to calibrate their instruments and refine the processing pipelines. Until one month after the end of Phase 1 Level 1 data will be available only to investigators affiliated with the instrument teams, interdisciplinary scientists (IDSs), or a small number of GIs (see §2.4.2 and §4.3.2), except for data from transients, which will be accessible immediately (see §4.3.5). The LAT team will release some sample Level 1 data during Phase 1 so that the data will become familiar to the scientific community unaffiliated with the LAT team; this release will assist the scientific community prepare proposals for the first Phase 2 GI cycle. During this Phase 1 scientists may publish any discoveries made with the data which they may access.

During Phase 1 the IDSs will work with the LAT team both in carrying out their proposed scientific investigations and in verifying the LAT data. During this first year the IDS investigations can use only data acquired by the planned operations of the GLAST Observatory, and cannot require pointed observations or special instrument operations; in this phase the IDSs will have access to the data through the instrument teams. In subsequent years, the IDSs may participate in the GI program to propose pointed observations.

During Phase 2 GLAST data will be available to the scientific community as soon as the required Level 1 processing preparing the data for scientific analysis has been performed and the resulting Level 1 data have been transmitted to the GSSC. This processing should be completed within a day after the Level 0 data arrives at the Level 1 pipeline at the IOCs, and the GSSC will load the Level 1 data into the open databases within a day after it receives these data. [The scientific community will be requested to honor the selection of the topic of an accepted GI proposal; the GSSC will post a list of the accepted proposals on its website.] There will not be a proprietary period for the data, as is dictated by the nature of the LAT data. Restricting to one investigator an entire observation that contains a source would be inefficient, given the LAT’s large FOV. The LAT’s energy-dependent point spread function, which is broad at low energy, necessitates analyzing a ~10° region around a source of interest; restricting access to portions of the FOV would make it difficult for investigators to study nearby sources.

4.3.2 LAT TEAM PROJECTS

The LAT team will undertake a number of scientific investigations specified in its successful proposal in response to AO 99-OSS-03. These investigations are:

- Preparation of a complete catalog of discrete sources, initially based on the Phase 1 sky survey, to be updated during Phase 2; the catalogs will be based on the data accumulated over the first 1, 2, and 5 years as well as the entire mission.
- Preparation of diffuse all-sky models and maps, including residual maps obtained after subtracting point sources and the estimated Galactic emission, to be updated throughout the GLAST observing program.
- Perform quick-look analysis of LAT data to identify transient sources and extract, for immediate public release, estimates of the source flux, position, and position error, as well as LAT data of the region around the transient at the time of the transient (see §4.3.5).

- Preparation of a complete catalog of GRBs detected by the LAT, including parameters such as fluence, peak flux, and duration (the observational data upon which this catalog is based will not be proprietary).

In addition to undertaking their scientific studies, during Phase 1 GIs and IDSs will assist the LAT team in performing essential, detailed in-orbit calibrations and refining analysis tools and procedures for use by the scientific community. The selected Phase 1 GIs are expected to understand the special technical requirements of the analysis and to support the development of scientific analysis software.

As part of the Phase 1 investigations the LAT team will refine the Level 1 processing pipeline. Therefore it is anticipated that the Level 1 processing will be repeated during this first year. The GSSC's backup Level 1 processing pipeline will be updated to reflect the refinements made by the LAT team. Level 1 data for the full 12 months of the sky survey should be processed, validated, calibrated, delivered and made available to the investigator community 1 month after Phase 1 concludes.

The all-sky map and the first year source catalog, both higher level LAT data products, are to be delivered to the GSSC within 30 days following the end of the survey. Preliminary all-sky maps, exposure maps and point source catalog will be made public during Phase 1 one month before the due date of the second NRA.

4.3.3 GBM TEAM PROJECTS

The GBM team will undertake a number of scientific investigations specified in its successful proposal in response to AO 99-OSS-03. These investigations are:

- Production of prompt GRB locations that will allow repointing of the spacecraft and/or facilitate prompt follow-up observations by ground-based instruments or other spacecraft.

- Preparation of a complete spectral catalog of time-resolved model fit parameters for GBM-triggered GRBs, using joints fits with LAT data where appropriate.

- Preparation of a catalog of GRBs detected by the GBM using both the on-board trigger and a ground-based *post facto* search, including parameters such as fluence, peak flux, and duration. Note that the observational data upon which this catalog is based will not be proprietary.

4.3.4 GUEST INVESTIGATOR (GI) PROGRAM

Approximately 12 Phase 1 guest investigations will be accepted, about 5-10 for analyzing LAT data and 1-2 for GBM data. GIs may propose to analyze GLAST observations, to perform observations at other wavelengths, or to undertake correlated theoretical investigations. The selected GIs may study any source, but cannot request scheduled Phase 1 observations that will disturb the all-sky survey; however GIs may propose TOOs. Since the instrument teams will refine their understanding of the instruments during the Phase 1 survey, GI investigations that require analysis of GLAST data during this phase will, of necessity, require working closely with the instrument teams.

During Phase 2 approximately 100 GI proposals will be accepted. The GI program will drive the observing plan, although continued survey mode observations may be the most effective observing strategy. The GIs and IDSs may propose any observations consistent with the spacecraft constraints. A small fraction of the observing time will be needed to re-calibrate or test the science instruments.

Instrument team members may propose observations during Phase 2. In addition, they may receive funding to supplement the funding they receive from the instrument teams.

The type of GI participation and the rules for access to the data will be defined by the NRAs released before each cycle of the GI program. The NRA for Phase 1 will be issued approximately one year before launch, and subsequent NRAs will be issued yearly. A compendium of the topics of all GLAST scientific investigations being undertaken by the LAT and GBM teams and by the selected GIs will be posted on the GSSC's website.

Five types of guest investigations have been identified, as shown by Table 4-2. The first four types require GLAST data, and are defined by two criteria: 1) the investigation may require either Level 1 or Level 2 data; and 2) the investigation may or may not require scheduled observations. Observations that do not require scheduling may be either archival data or data that will be acquired in the upcoming guest investigation cycle while GLAST continues to survey the sky. The fifth type of investigation is correlative or theoretical studies supporting the GLAST mission or its observations. It is not anticipated that sufficient Level 2 (or higher) data will have been generated during the survey to warrant Phase 1 guest investigations using these data.

Table 4-2: Types Of Guest Investigator Proposals

	Using Level-1 processed data	Using Level-2 or higher processed data
Data analysis and research with existing or archival GLAST data	**Type 1** Phases 1, 2	**Type 2** Phase 2
Guest investigations requiring scheduled observations	**Type 3** Phase 2	**Type 4** Phase 2
Correlative research and theoretical studies	**Type 5** Phases 1, 2	

Key Projects may be carried out within the GI program. These are defined as large scientific investigations involving new pointed or scanning observations, or large scale use of the GSSC's databases. Anyone my propose Key Projects, including instrument team members and IDSs. Key Projects may be based on observations obtained during any part of the mission.

4.3.5 TRANSIENT POLICY

The GLAST instrument teams will release data on transient gamma ray sources to the community. The instrument PIs, in consultation and collaboration with the Users' Community, the Project Scientist and the SWG, shall release data of interest as soon as practical. The decisions on which data are to be released will be based on advice from scientists analyzing the data and an evaluation of the scientific interest that the data might generate. They will follow the general guidelines below:

1) Gamma-ray bursts: All data on gamma-ray bursts that trigger either the LAT or GBM will be released. The prompt data release will include direction, fluence estimate and other key information about the burst immediately on discovery. Individual photon data and technical information for their analysis will be released as soon as practical. This guideline also covers non-gamma ray burst triggers from the GBM, e.g., solar flares. The definition of "practical" will be refined based on data-processing limitations and feedback to the GLAST instrument teams from observatory users such as GIs and members of multiwavelength collaborations monitoring GLAST sources. If one of the instruments does not trigger on a gamma-ray burst that is detected by the other instrument, information on any detected signal or an upper limit will be released as soon as practical.

2) Blazars and some other sources of high interest: 10-20 pre-selected sources from the 3rd EGRET catalog will be monitored continuously and the fluxes and spectral characteristics will be posted on a publicly accessible web site by the LAT instrument team. This list will be made available prior to launch, for comment by the user community. Another 10-20 scientifically interesting sources will be added to this list during the survey. The list will include some known or newly discovered AGN selected to be of special interest by the TeV and other communities as well as galactic sources of special interest discovered during the survey. Finally, sources whose fluxes may trigger a GI-defined TOO will also be monitored.

3) New transients: The community will be notified when a newly discovered source goes above an adjustable flux level of about (2-5) x 10^{-6} photons (> 100 MeV) per cm^2 s for the first time. This corresponds to a peak counting rate of about 100 counts per hour in the LAT. The flux level is to be adjusted to set the release rate to about 1-2 per week.

A high flux derivative (TBD) observed for a source having a minimum flux (TBD) should also trigger a release when statistically significant at a TBD sigma level. The release rate for these sources should be included in the 1-2 per week overall release rate, and should be practical for the LIOC to implement.

The prompt data release for categories 2 and 3 will include information on source coordinates, flux and other key information such as critical timescales or spectral properties. The photon data and relevant information for data analysis will be released, including cautions about calibration and reliability, as soon as practical after discovery.

During Phase 1 the IOCs are the implementing centers. It is recognized that the capability to do this will be validated following launch and the capabilities to recognize these transients will probably evolve with time as the ground processing and analysis procedures are tested and improved. Implementation must take account of the practicality of implementation and the guidelines are subject to revisions based on the actual experience in implementation.

During the remainder of the mission (Phase 2) these release and implementation policies will continue to be reviewed and updated. The Project Scientist is responsible for implementation and review of this policy and will have the authority to modify the implementation procedures if required.

5 PRODUCTS

In this section the data products produced by the various ground system elements are presented in tabular form. These products are described in greater depth by the "Report of the GLAST Data Products Working Group," which will be converted into Interface Control Documents (ICDs) among the ground system elements. The identifier for each data product is taken from this report. Latency is defined as the time between the arrival of the last data required to produce the data product and delivery of the resulting product.

The data products in §5.1 and §5.2 will be delivered primarily as FITS files. In some cases data may be transferred through database mirroring, where the database of the receiving organization is updated to be identical to the database of the originating organization. However, in database mirroring all the information necessary to produce a corresponding FITS file must be provided; the definition in terms of a FITS file can therefore be used as a "meta-format" description.

All data products delivered to the GSSC will be loaded into databases for use during the mission and for archival preservation by the HEASARC afterwards. In general these databases will conform to HEASARC standards. If for operational reasons the GSSC maintains an "optimized database" in a format or architecture that does not conform to HEASARC standards, the GSSC will create and provide a HEASARC-standard database—data in FITS files ("archives" in HEASARC terminology) catalogued and indexed by metadata files ("databases" in HEASARC terminology).

In the following tables the first column provides the identifier for the data product that is transferred between ground elements, the level of the data and the name of the database the GSSC will maintain.

5.1 SCIENCE DATA PRODUCT SUMMARY

5.1.1 LAT

Table 5-1: LAT Science Data Products

Identifier/ Level/ Database	Product	Description	Delivered	Latency	Size	Produced by	Deliver to
MS-001 0 D0	LAT Level 0 Data	Level 0 data from the LAT—includes both science and housekeeping data	Per downlink	1 day	3 Gbyte per day	MOC	LIOC GSSC HEASARC
ML-002 NA D8	LAT alert	Alert generated by LAT to indicate an urgent problem or detection of a transient source	As received	TBD	TBD	MOC	LIOC GSSC GIOC HEASARC

LS-002 1 D1ev	Event list	List of all events telemetered to the ground with a large number of parameters describing the event reconstruction	Per downlink	1 day	250 Mbyte per day	LIOC	GSSC HEASARC
LS-005 1 D2	Pointing and livetime history	LAT orientation and mode at 4 s intervals; necessary for exposure	Per downlink	1 day	1.5 Mbyte per day	LIOC	GSSC HEASARC
SS-002 1 D1ph	LAT photon list	Events in LS-002 identified as photons—includes only those parameters necessary for the current IRF parameterization	Per downlink	1 day	25 Mbyte per day	GSSC	GSSC HEASARC
SS-003 2 D23	LAT sky map	Map of photons, exposure and intensity over entire sky and in regions of interest (e.g., 3C 273/3C 279 and Galactic anticenter)	Periodically	1 day	TBD	GSSC	GSSC HEASARC
LS-010 3 D7	Interstellar emission model	Model for diffuse gamma-ray emission from the Milky Way, input for high-level data analysis; will be refined using GLAST data	Initial model updated periodically	N/A	40 Mbyte	LIOC	GSSC HEASARC
NA 3 D4	Pulsar Ephemeride s	Ephemerides of pulsars likely to be GLAST sources.	Periodically	N/A		Pulsar Committe e	GSSC LIOC HEASARC
LS-007 2 D9	LAT transient data	Summary information for transient sources (GRBs, solar flares, and AGN flares) derived from LAT event data	Per transient	1 day	100 kbyte	LIOC	GSSC HEASARC
LS-008 3 D5	LAT source catalog	Table of detected gamma-ray sources with derived information	On update	N/A	10 Mbyte	LIOC	GSSC HEASARC
LS-009 3 D6	LAT Burst Catalog	List and characterization of gamma-ray bursts; location, duration, intensity	On update	N/A	TBD	LIOC	GSSC HEASARC

The primary LAT Level 1 data product (LS-002) is the set of all the events that were reconstructed from the Level 0 data that were downlinked to the ground. The data product that the LIOC will provide to the GSSC will include a large set of parameters resulting from the event reconstruction describing the event, but will not describe the “hits” in the LAT’s components. The categorization of an event as a photon or non-photon will be one of the provided parameters. The GSSC will store the LS-002 data in the D1ev database. At the GSSC those events categorized as photons will be extracted from LS-002 along with only the specific parameters relevant to calculating the response function for that photon (data product SS-002) and stored in the D1ph database. Thus D1ph will be simply a subset in both size and content of D1ev. Most users will analyze photon lists extracted from D1ph, and the standard analysis tools will require only the photon parameters provided in D1ph. Utilities will be provided to access events from D1ev, but the GSSC will not supply the software to use the events and parameters not included in D1ph.

5.1.2 GBM

Table 5-2: GBM Science Data Products

Identifier/ Level	Product	Description	Delivered	Latency	Size	Produced by	Deliver to
MG-001 0 D0	GBM Science Data	Level 0 data from the GBM	Per downlink	1 day	130 Mbyte per day	MOC	GIOC GSSC HEASARC
MG-002 N/A D24	GBM alert	Alert generated by GBM to indicate an urgent problem or detection of GRB	As received	TBD	TBD	MOC	GCN LIOC GIOC GSSC HEASARC
GS-001 1 D10	Continuous data	Count spectra from continuous science telemetry	Per downlink	1 day	250 M per day (TBR)	GIOC	GSSC HEASARC
GS-001, GS-002, GS-003 1 D11	Burst trigger data	Time-tagged counts from triggered events, plus 4000 s of background data centered on trigger time and appropriate response functions	Per burst	1 day	20-35 Mbyte per burst	GIOC	GSSC HEASARC
GS-007 2 D12	Trigger catalog	List and characterization of triggered events	On update	Immediate	TBD	GIOC	GSSC HEASARC
GS-009 3 D13	GRB catalog	List and characterization of detected GRBs (including GRBs not triggered on-board)	On update	Immediate	TBD	GIOC	GSSC HEASARC

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GS-008 3 D14	Burst spectra catalog	Catalog of deconvolved spectra	On update	Immediate	TBD	GIOC	GSSC HEASARC

5.2 HOUSEKEEPING AND OPERATIONS DATA PRODUCT SUMMARY

5.2.1 SPACECRAFT

Table 5-3: Spacecraft Operations Data Products

Identifier/ Level	Product	Description	Delivered	Latency	Size	Produced by	Deliver to
MS-001 0 D21	As flown timeline	History of commands actually executed	Weekly (TBD)	1 day	TBD	MOC	GSSC LIOC GIOC HEASARC
MS-002 0 D0	Spacecraft Level 0 data	Housekeeping data specific to the spacecraft	Per downlink	1 day	45 Mbyte per day	MOC	GSSC LIOC GIOC HEASARC
MS-003 0 D22	Spacecraft alert	Alert generated by SC to indicate an urgent problem	As received	TBD	TBD	MOC	GSSC LIOC GIOC HEASARC

5.2.2 LAT

Table 5-4: LAT Operations Data Products

Identifier/ Level	Product	Description	Delivered	Latency	Size	Produced by	Deliver to
ML-001 0 D0	LAT House-keeping	Level 0 engineering data; also appears in 5.1.1	Per downlink	1 day	TBD	MOC	LIOC GSSC HEASARC
LS-001 N/A D18	Instrument commands	Commands sent by LIOC through GSSC, whether executed or not	As needed	None	TBD	LIOC	GSSC HEASARC
LS-003 N/A D19	Low-level calibration	Calibration information for the subsystems, e.g., dead, off or noisy TKR strips, ACD tile status and PMT gains, CAL status and light sharing.	Weekly	1 week	TBD	LIOC	GSSC HEASARC

LS-004 2 D3	Instrument Response Functions	Full IRF for all possible parameters	On update	N/A	5 Mbyte (TBR)	LIOC	GSSC HEASARC
LS-006 N/A D20	Configura-tion history	Detailed LAT configuration history, all registers of each subsystem as updated	On update	12 hrs	1 M	LIOC	GSSC HEASARC

5.2.3 GBM

Table 5-5: GBM Operations Data Products

Identifier/ Level	Product	Description	Delivered	Latency	Size	Produced by	Deliver to
MG-001 0 D0	GBM Level 0 data	Level 0 data from the GBM	2/day	1 day	TBD	MOC	GIOC GSSC HEASARC
GS-004 N/A D17	Instrument commands	Commands sent by GIOC through GSSC, whether executed or not	As needed	None	TBD	GIOC	GSSC HEASARC
GS-005 N/A D16	Energy calibration	History of detector gains & energy resolutions	Weekly	1 day	500 kbyte	GIOC	GSSC HEASARC
GS-006 1 D15	Instrument response calibration	Tables of fiducial detector response parameters	On update	Immedi ate	50 Mbyte	GIOC	GSSC HEASARC

5.3 ANALYSIS SOFTWARE

The standard analysis environment will consist of tools that run on the users' computers and tools and databases on the GSSC's servers. Users will access the databases through the GSSC's website. The tools that the users download to their computers will be FTOOLS within the HEASARC's HEAdas system. Therefore, these tools will read and write FITS files, will use the PIL parameter interface, and will access response function data stored in a CALDB file structure. The distributed code will be supported on both Windows and LINUX platforms and will include all necessary libraries (e.g., those necessary for graphics), and users may choose either binary executables or source code. The software will be downloaded from the GSSC's website, and will be packaged using the HEASARC's standard system. While it will be possible to run most of the tools ballistically—without user interaction once the parameters are entered—it will also be possible to run them interactively and from within a GUI interface.

Extensive documentation will be provided through the GSSC's website on the use, applicability and methodology of the software.

Listed below are the Level 2 software tools that the GSSC will provide to the scientific community. The tools will be described in greater detail in software requirements documents.

5.3.1 LAT TOOLS

The LAT tools are divided into utilities, analysis tools and simulators. Many of the GRB tools can be used for both LAT and GBM data.

Table 5-6: LAT Utilities

ID	Name	Description
U1ph	Photon data extractor	Basic front end to the photon database (D1ph). Runs on the GSSC's servers.
U1ev	Event data extractor	Basic front end to the event database (D1ev). Runs on the GSSC's servers.
U2	User-level data extraction environment	Allows the user to make further cuts on the photons extracted from the event summary database, including energy-dependent cuts on angular distance from a source position
U3	Pointing/livetime history extractor	Basic front end to the pointing, livetime, and mode history database (D2). Runs on the GSSC's servers.
U4	Exposure calculator	Uses IRFs and pointing, livetime and mode history (D2) to calculate the exposure quantities for the likelihood analysis (A1)
U5	Interstellar emission model	Not software per se, although the model itself will likely have parameters (or more complicated adjustments) that need to be optimized once and for all, in concert with an all sky analysis for point sources.
U6	Map generator	Binning of photons, regridding of exposure, coordinate reprojection, calculation of intensity
U7	Source model definition	Interactive construction of a model for the region of the sky by specifying components such as the interstellar emission, point sources, and extended sources, along with their parameter values; the resulting models can be used in the likelihood analysis (A1) and the observation simulator (O2)
U8	IRF visualization	Extracting PSF, effective areas, and energy distributions from the CALDB (D3) for visualization
U9	Catalog access	Extracting sources from catalogs, including LAT source catalog (D5)
U10	Gamma-ray arrival time barycenter correction	For pulsar analysis
U11	Pulsar ephemeris extractor	Interface to the pulsar ephemeris database (D4)
U12	Pulsar phase assignment	Using ephemeris information from U11 and barycenter time corrected gamma rays from U10, assigns phases to gamma rays
U13	GRB visualization	Displays various types of GRB lightcurves and spectra
U14	LAT GRB DRM generator	Generates the detector response matrix appropriate for fitting binned LAT GRB spectral data.

U15	Alert database access	Accesses LAT, GBM and spacecraft alert databases (D8, D24 and D22)
U16	Burst catalog access	Accesses LAT and GBM burst catalogs (D6, D13). Also accesses GBM trigger catalog.
U17	LAT transient database access	Accesses LAT transient database (D9).
U18	Command database access	Accesses command databases (D21, D18, D17)
U19	Configuration history access	Accesses the LAT configuration history (D20)

Table 5-7: LAT Analysis Tools

ID	Name	Description
A1	Likelihood analysis	Point source detection, characterization (position, flux, spectrum), generalized models for multiple/extended sources
A2	Source identification	Quantitative evaluation of the probability of association of LAT sources with counterparts in other catalogs
A3	Pulsar profiles	Phase folding of gamma-ray arrival times (after phases are assigned by A3) and periodicity tests
A4	Pulsar period search	Search for periodic emission from a point source
A5	GRB event binning	Bins events into time and energy bins
A6	GRB rebinning	Rebins binned GRB data into larger time and energy bins
A7	GRB temporal analysis	Analyzes GRB lightcurves using various techniques such as FFTs, wavelets, etc.
A8	GRB binned spectral analysis	Fits binned spectra; may be XSPEC
A9	GRB unbinned spectral analysis	Fits event data with spectral models
A10	GRB spectral-temporal physical modelling	Fits a GRB physical model to LAT or LAT+GBM data

Because the LAT PSF will be broad, particularly at low energy where most of the photons will be detected, the photons from nearby sources will overlap spatially, and the analysis of most persistent sources must be spatial and spectral. The likelihood tool, A1, will use the likelihood for the spatial and spectral distribution of the observed photons for analyses such as source detection and spectral fitting.

Table 5-8: LAT Simulators

ID	Name	Description
O1	Livetime/pointing simulator	Generates simulated pointing, livetime, and mode histories (analogue of D2) for a specified time range and observing strategy. This should be available as a tool, but probably most generally useful will be precomputed simulated D2 databases, which can be used subsequently for any study with O2.
O2	High-level observation simulator	Generates gamma rays according to the instrument response functions (i.e., after detection, reconstruction, and background rejection), bypassing the instrument simulation step

5.3.2 GBM TOOLS

Table 5-9: GBM Tools		
ID	**Name**	**Description**
G1	Background-creation tool	Calculates the GBM background channel-by-channel from observations before and after the burst.
G2	GBM DRMGEN	Calculates the GBM Detector Response Matrix for a particular burst.
G3	Burst spectra catalog access	Accesses burst spectra catalog (D14)

6 RESPONSIBILITIES OF THE GROUND SYSTEM ELEMENTS

The activities of the different ground system elements during the mission are described in the end-to-end data flow narrative (§4.2) and the data products each will produce are detailed in §5. In this section the data-related responsibilities are presented by element.

6.1 THE MISSION OPERATIONS CENTER (MOC)

The MOC will be located at GSFC, and will be staffed by the FOT. The MOC will be responsible for the link between the spacecraft and the ground system elements, for monitoring the health of the spacecraft, for formatting the commands uplinked to the spacecraft, for anomaly detection and resolution, and for Level 0 processing of all the data from the spacecraft.

6.1.1 COMMUNICATIONS

The MOC will receive data from the Space Network (SN) during and after each real-time contact. The MOC will verify that all data packets were received in acceptable condition, and will request the retransmission from WSC or the spacecraft of missing or damaged packets, depending on where the data were lost. Consequently, WSC will store the raw telemetry for at least 7 days after its downlink. The MOC will perform the Level 0 processing, which time-orders the packets and removes any repeated or erroneous packets. The MOC is not responsible for removing repeated data between the end of one scheduled Ku-band contact and the beginning of the subsequent scheduled contact. Subsequently the MOC will transmit the LAT and GBM Level 0 data to the LIOC and GIOC, respectively. All the Level 0 data will be sent to the GSSC for archiving. The MOC will retain the raw telemetry for the duration of the mission.

The MOC will develop and test its ground system software. Thus the MOC will participate in ground system tests to ensure that data will flow properly into, within and out of the MOC, and that the software packages perform properly. These tests will be described in the Ground System Test Plan.

6.1.2 SPACECRAFT MONITORING

The MOC will monitor the health of the spacecraft using the real time spacecraft engineering data during each Ku-band contact. The MOC will also analyze select engineering and instrument data after each contact. The GLAST Project Scientist, the GSSC and the IOCs will be notified if any anomalies are detected. The MOC will maintain a database of all telemetry and command mnemonics; this database will be archived at the GSSC. Time histories of selected spacecraft parameters will also be archived at the GSSC.

6.1.3 SPACECRAFT COMMANDS

The MOC will receive instrument commands to be uplinked to the observatory through the GSSC. In general, MOC will create a weekly observatory timeline including the science timeline from the GSSC, the spacecraft commands, and the instrument commands originating in the IOCs. However, if needed, commands and flight software upgrades can be uplinked in between the uplink of the observatory timeline. The observatory timeline and most commands will be uplinked on the S-band link during a scheduled contact. Large flight software upgrades and time critical commands (e.g., to save an instrument or the observatory) will be uplinked through TDRSS MAF. The MOC will check whether commands satisfy engineering constraints. The MOC will create, and the GSSC will archive, an as-flown timeline.

The relevant IOC will send to the GSSC instrument commands or flight software updates, along with the time the command or update is to be implemented. The GSSC will evaluate whether the implementation of the command or update is consistent with the science timeline (e.g., instrument parameters should not be changed in the middle of a pointed observation); if the impact is unacceptable, the GSSC will request that the command or update is rescheduled.

6.2 THE LAT INSTRUMENT OPERATIONS CENTER (LIOC)

The LIOC will be located at Stanford University, the LAT PI institution. The LIOC will be responsible for communications with the MOC, monitoring the performance of the LAT, the Level 1 processing and transmitting the results to the GSSC. Before launch the LIOC will be responsible for: developing the LAT Instrument Response Functions (IRFs) as part of the effort to calibrate the LAT; constructing the Level 1 processing pipeline; and developing the science analysis tools. During Phases 0 and 1 the LIOC will refine the processing pipeline based on the LAT's on-orbit performance. During the mission the LIOC will: perform the Level 1 processing for both the scientific community and the LAT team's scientific investigations; monitor the LAT's performance; and support the project in operating the LAT.

6.2.1 INSTRUMENT RESPONSE FUNCTIONS (IRFS)

In calibrating the LAT before launch, the instrument team will characterize the response of the instrument to external photon sources. Experimental data will be used to verify and validate the mathematical model of the instrument that will then be used for Monte Carlo simulations of the LAT's response. The Monte Carlo simulations and experimental data will determine the instrument response as a function of relevant photon parameters such as incident direction and energy. These simulations will produce lists of events that will be formatted as if they were real data and used to test the analysis software. The functional form of the IRFs will be abstracted from these simulations. For details of the calibration of the LAT see the LAT Calibration Plan. The LIOC will provide the IRFs to the GSSC, along with a subset of the simulated data.

The inputs and outputs to the IRFs are likely to be functions of many parameters such as the energy, angle and position of the photon interaction in the LAT. Because most LAT data will be acquired while the spacecraft is scanning the sky, most observations will result in counts with different photon incident directions relative to the LAT. Thus the analysis of LAT data will require a compact yet accurate representation of the IRFs that can be utilized rapidly, particularly by the average investigator. Consequently, the LIOC will develop a representation of the IRFs that meets the requirements developed by the LIOC-GSSC software working group (see §6.2.3). The calibration data will be stored within the HEASARC's Calibration Database (CALDB) system. Thus the IRFs and supporting files delivered to the GSSC will conform to the HEASARC FITS standards (see §6.5.2.1).

6.2.2 LEVEL 1 PROCESSING PIPELINE

The Level 0 data will consist of the position and pulse heights of interactions in different parts of the LAT induced both by gamma rays and by cosmic rays that survived the initial analysis cuts aboard the spacecraft. The Level 1 data will be lists of events characterized by quantities such as the apparent direction, energy, and time. The Level 1 processing will consequently be quite involved, and will be implemented by a software pipeline consisting of a series of programs. The LIOC will be responsible for developing the programs for the Level 1 processing; the GSSC will install a backup copy of the resulting Level 1 processing pipeline. Although this pipeline will ultimately be archived at the HEASARC, its internal data representation need not conform to the standards of the astrophysical community; the final products are FITS files. Once real data become available after launch, the Level 1 processing will undoubtedly have to be refined: calibration parameters may change, different fitting tolerances may be necessary, data cuts may be modified, etc. The LIOC will update the Level 1 processing pipeline, particularly during the first year after launch. During this first year the Level 0 data will be reprocessed a number of times; the data products are defined to identify the files resulting from such reprocessing. The GSSC's backup Level 1 processing pipeline will be updated to mirror the current state of the LIOC's pipeline. The GSSC's backup pipeline will be tested to ensure that it duplicates the processing by the LIOC's pipeline.

During all mission phases the LIOC will operate the Level 1 processing pipeline for both the scientific community and the LAT team. The GSSC will activate its backup pipeline only in an emergency and with the concurrence and supervision of the LAT team. As part of its standard processing the LIOC will scan the Level 1 data for transients; new sources or significant variability of known sources will be reported on LAT and GSSC public websites. During all phases standard Level 2 data products will become public as soon as available (see §4.3.5). A significant transient may be reported by an IAU circular, and may initiate a TOO. As part of its routine processing, the LIOC will screen and classify burst triggers, and will provide the GSSC with GRB parameters such as intensity, fluence, spectrum, and duration. The LIOC will provide updated burst locations to the scientific community through GCN Notices, and burst parameters through GCN Circulars.

In conjunction with the other ground elements, the LIOC will test the ground system software before launch. Thus the LIOC will participate in various tests of this software to ensure that data will flow properly within and among the various ground organizations, and that the software packages perform properly. These tests will be described in the Ground System Test Plan.

6.2.3 SCIENCE TOOLS SOFTWARE

The GSSC and LAT team have jointly defined the Level 2 science tools (listed in §5.3) for deriving scientific results from the Level 1 data, but the LAT team is responsible for managing the development. The LAT team will use these tools for their scientific investigations (e.g., the sky survey and point source catalog), while the GSSC will make these tools available to the scientific community unaffiliated with the LAT team. The LIOC and GSSC have convened a software working group with HEASARC representation—with a co-lead and equal representation from each organization—to maintain the list of required software packages in §5.3, establish standards for this software, and set release dates for the required software produced by members of the LAT team and by GSSC scientists. The software will conform to the standards of the HEASARC, and will use FITS format files for I/O (see §6.5.2.1). The software will be accompanied by documentation describing the applicability of the underlying methodology, the algorithms implemented, and the use of the code.

6.2.4 MISSION SUPPORT

The LIOC will monitor the LAT's performance using the engineering data that are included with the science data. The LIOC will produce time histories of relevant instrument parameters (e.g., PMT gains, detector noise occupancy), and will provide these time histories to the GSSC where they will be archived. Within the LIOC, a separate database of highly energetic cosmic rays will be accumulated to assist in the determination of the relative positions of the SSDs in the TKR. Similarly, other parameters of diagnostic or calibration use may be accumulated. Examples might include histograms of TKR strip hits to identify bad strips, histograms of ACD PMT output to identify malfunctioning PMTs, statistics on ACD tile response, and histograms of CAL readout response to identify noisy or dead CAL channels. A standard report of instrument health will be generated weekly and posted to websites maintained by the LIOC and the GSSC. Separate status reports may be considered for these sites that are open to the general public as well as ones useful to the scientific community.

Periodically the LAT team will run the LAT in an engineering mode to test its health and status and to re-calibrate the instrument. Ideally the schedule for these tests should be developed at the beginning of the yearly GI cycles to minimize disrupting the mission timeline, but on occasion an unanticipated test may be required. The LIOC will request that the GSSC schedule the test. A history of these tests will be maintained and archived by the GSSC.

The LAT team will update the instrument's flight software based on in-orbit operational experience. In particular, the LAT team will turn off malfunctioning components (e.g., ACD tiles or TKR modules), or will mask out components that have failed. The LIOC will prepare a command set implementing the flight software update. The command set will be sent to the MOC through the GSSC, and then uplinked to the spacecraft through the TDRSS MAS.

The LAT team will produce and maintain a model of the diffuse gamma-ray emission. This model is necessary for separating the point source flux from the spatially variable diffuse emission, but it is also intrinsically interesting.

6.3 THE GBM INSTRUMENT OPERATIONS CENTER (GIOC)

The GIOC will be located at the NSSTC in Huntsville, AL. Before launch the GIOC will be responsible for: developing the GBM IRFs as part of the effort to calibrate the GBM; constructing the Level 1 processing pipeline; and developing the science analysis tools. Immediately after launch the GIOC will refine the processing pipeline based on the GBM's on-orbit performance. During the mission the GIOC will: perform the Level 1 processing for both the scientific community and the GBM team's scientific investigations; monitor the GBM's performance; and support the project in operating the GBM.

6.3.1 INSTRUMENT CALIBRATION

GBM calibration activities at the GIOC fall into two categories: channel-to-energy conversion and detector response. Algorithms for conversion of pulse height channels to energy are determined for each detector prior to launch, based on laboratory calibrations with standard sources and electronic test pulses, and as a function of operating temperature. In-flight variations are monitored by measuring the pulse height channel of one or more emission lines in the background spectra, and corrections are applied as needed to the pre-launch algorithms.

Since the GBM detectors are unshielded, the incident photons consist of three components: direct, spacecraft-scattered, and atmospheric-scattered. The direct and spacecraft-scattered components depend on the location of the source relative to the detector. The atmospheric-scattered component is also dependent on the relative location of the geocenter. Storing a set of response matrices for every possible combination of source and geocenter angles is inefficient. Fortunately, various symmetries simplify the problem. Using a combination of pre-launch laboratory measurements and Monte Carlo simulations, the GBM response will be parameterized as a set of fiducial tables and algorithms from which a response matrix may be generated for an arbitrary set of source and geocenter angles, and energy bins. The response matrices will be validated in-flight by the GIOC. The Monte Carlo simulations can be formatted as if they were real data, and used to test the analysis routines. The GIOC will provide both the files of simulated events and the IRFs to the GSSC. The joint GSSC-GIOC software working group (see §6.3.4) will establish the standards for the representation of the GBM's IRFs. The calibration files will be stored within the CALDB system and will conform to HEASARC FITS standards (see §6.5.2.1).

6.3.2 LEVEL 1 PROCESSING PIPELINE

GBM Level 1 data processing consists of decoding the telemetry data packets, scaling all engineering data to engineering units, separating and assembling time-resolved spectra, time-tagged events and necessary related information, classifying triggers, and calculating standard parameters for selected trigger types. The Level 1 processing pipeline will produce two main standard data products: continuous data files and burst trigger data files. Additional products will include catalogs of triggered GRBs, selected other trigger types, exposure maps and energy spectra. As part of its routine processing, the GIOC will screen and classify GBM triggers, and will provide the GSSC with updated GRB parameters, such as location, intensity, fluence, spectrum, and duration. The GIOC will provide updated positions to the scientific community through GCN notices, and burst parameters through GCN Circulars.

The GIOC will be responsible for developing the programs for the Level 1 processing, which will be provided to the GSSC. Once real data become available after launch, the Level 1 processing may have to be refined because calibration parameters may have changed. Reprocessing of the Level 0 data is anticipated, particularly during the first year. The GIOC will update the Level 1 processing pipeline, particularly during the first year after launch. The GSSC's backup pipeline will be modified to reflect the refinements made by the GIOC. The GIOC and GSSC will compare the results of their processing pipelines to ensure they agree. During the mission the GIOC will operate its Level 1 processing pipeline for both the astronomical community and the GBM team. The GSSC will activate its pipeline only in an emergency with the concurrence and supervision of the GIOC.

In conjunction with the other ground system elements, the GIOC will test the ground system software before launch. Thus the GIOC will participate in various tests of this software to ensure that data will flow properly within and among the various ground system elements, and that the software packages perform properly. The tests will be described in the Ground System Test Plan.

6.3.3 LEVEL 2 PROCESSING

High-level GBM Level 2 processing falls into several categories: spectral analysis of GBM data, alone or in combination with data from the LAT or instruments on other satellites; temporal analysis of bursts or other transient events; sky distributions of GRB sub-classes; and searches for untriggered bursts or other types of transients. Monitoring of persistent and longer-term transient sources is possible with the GBM using pulse-folding and Earth occultation techniques, as was done for BATSE; however the analysis of such sources and the software to perform this analysis are not part of the presently planned capabilities of the GIOC.

6.3.4 SCIENCE TOOLS SOFTWARE

The LAT science tools for bursts will also be able to analyze GBM data, and therefore only GBM-specific tools (listed in §5.3) are necessary, although the GBM team may contribute additional tools based on their burst analysis experience. The GBM team will use these tools for their scientific investigations, while the GSSC will make these tools available to the astronomical community. The GIOC and GSSC have convened a software working group with HEASARC representation—with a co-lead and equal representation from each organization—that will maintain the list of required software packages, establish standards for this software, and set release dates for the software produced by members of the GBM team and by GSSC scientists. The software will conform to the standards of the HEASARC by using FITS format files for I/O (see §6.5.2.1). The software will be accompanied by basic documentation describing the applicability of the underlying methodology, the algorithms implemented, and the use of the code.

6.3.5 MISSION SUPPORT

The GIOC will monitor the GBM’s performance using the engineering data that are included with the science data. The GIOC will produce time histories of relevant instrument parameters (e.g., PMT gains), and will archive these time histories at the GSSC. A standard report of instrument health will be generated weekly and posted to websites maintained by the GIOC and the GSSC. Separate status reports may be considered for these sites that are open to the general public as well as ones useful to the scientific community.

The GBM team will update the instrument’s flight software based on in-orbit operational experience. The GIOC will prepare a command set implementing the flight software update. The command set will be sent to the MOC through the GSSC and then uplinked to the spacecraft.

6.4 THE GLAST SCIENCE SUPPORT CENTER (GSSC)

The GSSC is located at the Laboratory for High Energy Astrophysics (LHEA) at GSFC. The GSSC is part of the Office of Guest Investigator Programs (OGIP) in LHEA. The GSSC is the interface between the GLAST mission and the scientific community unaffiliated with the instrument teams, and therefore has the responsibility of organizing the GI program and of providing GIs and other scientists with data and analysis software. The GSSC is also responsible for the science timeline. Finally, the GSSC will support the Project in running the mission.

The GSSC combines the functions often performed by a Science Operations Center, which carries out high level data processing, archiving and mission planning, and a Guest Observer Facility, which supports GIs. The GSSC will not support a dedicated facility to which investigators come to obtain and analyze data.

6.4.1 ORGANIZATION OF THE GUEST INVESTIGATOR PROGRAM

The GSSC is responsible for assisting NASA HQ in preparing the NRAs for each GI cycle, organizing the proposal process, supporting NASA HQ by organizing the evaluation of guest investigation proposals, and implementing the guest investigations selected by NASA HQ.

The GSSC will prepare the text for each NRA based on requirements from NASA HQ. Thus the GSSC will write, and subsequently revise, descriptions of the instruments, the analysis software, and the policies of the GI program. As appropriate, the instrument teams will provide necessary technical updates in support of the preparation of the NRAs. The NRAs will be revised, reviewed, ratified and released by NASA HQ.

The GSSC will make available to proposers the tools necessary to evaluate the feasibility of their proposed observations. Specifically, the GSSC will make available software to simulate the observations, and analysis software to analyze simulated data. This software may use simplified IRFs to speed up the simulations. As the mission progresses, the GSSC will develop analytic estimates of the instruments' sensitivities that can be used to estimate the detectability of sources of a given intensity. The GSSC will also provide tools to evaluate the efficacy of different observing modes for the proposed observations. Finally, the GSSC will maintain a library of scientific results from GLAST and past gamma-ray missions.

The GSSC will organize the evaluation of the submitted proposals. Thus the GSSC will assist NASA HQ by receiving and cataloging the proposals, recommending peer reviewers, distributing the proposals to the peer reviewers, convening the peer review panels, and collating the evaluations of the peer review panels. The GSSC will advise the panels on the impacts of proposals on the timeline. NASA HQ will select the peer review committees and make the final proposal selection. Following guidelines from NASA HQ, the GSSC will establish the policies governing the peer review (e.g., conflict-of-interest rules).

6.4.2 SCIENCE TIMELINE

The GSSC is responsible for generating GLAST's observing plan. Annually, the Project Scientist will appoint a GLAST Timeline Committee, chaired by the Project Scientist (or a designee), and consisting of GSSC, LAT and GBM team representatives along with mission operation experts. This committee will plan the mission's observing timeline. The GSSC will generate the weekly science timeline to implement a week's worth of the yearly observation. The science timeline will be posted on the GSSC website.

During Phase 1 (the first year of scientific operations) the timeline will be simple: GLAST will conduct an initial all-sky survey that will be interrupted only by Project Scientist-approved TOO observations and autonomous repointings following transients and GRBs.

During Phase 2 the GLAST Timeline Committee will meet once a year to schedule the observations requested by the guest investigations selected by NASA HQ following the peer review of proposals submitted in response to yearly NRAs. The Timeline Committee will be guided by: the scientific priorities assigned the observations by the peer review panels; SWG priority policies and guidelines; and constraints imposed by the MOC (e.g., Earth avoidance, telemetry contacts) or the IOCs (none currently known).

With the approval of the Project Scientist, the GSSC will modify the science timeline to accommodate commands to the instruments or the spacecraft. In particular, one of the IOCs may request that the relevant instrument be placed in engineering mode for a period of time. Ideally the schedule of such tests will be developed at the beginning of the annual GI cycle, but occasionally a test may be required on a shorter timescale. Similarly, a TOO will require modifications of the timeline (see §6.4.5).

The GSSC will develop a tool to simulate GLAST observations to support timeline planning and to evaluate sky survey techniques for uniformity of coverage over various timescales, for frequency of full sky coverage, and for spacecraft feasibility.

6.4.3 GUEST INVESTIGATOR SUPPORT

The GSSC will make data available to a GI as the GI's Phase 2 observations occur. Analysis software, ancillary data, and related documentation will be available on the GSSC's website. The GSSC will furnish online and human expertise in analyzing the data. The GSSC will also support a library with catalogs and other ancillary information to assist the investigator community.

Once an observation requested by a GI has undergone Level 1 processing and has been placed into the GSSC's database, the GI will extract the relevant observational data from the database, and may transmit it electronically it to his/her home institution (e.g., via FTP). Given the universal availability of computer resources and internet access, the GSSC will not operate a dedicated facility to which investigators come to analyze data, nor will the GSSC distribute the data via physical media (e.g., tapes or CDs) except by special request.

The GSSC will make available analysis software (described in §5.3) that the GIs can download from the GSSC's website. This software will also generate the necessary IRFs. The software will be accompanied by extensive documentation about its use and about the algorithms implemented. The GSSC will also provide ancillary data necessary for the data analysis such as the diffuse emission model and the pulsar timing database. The LAT team will provide the diffuse emission map, and update it periodically. An independent Pulsar Committee will be responsible for obtaining the pulsar ephemerides; the GSSC will maintain the resulting database. The GSSC website will make accessible to GIs (and all interested scientists) the GLAST point source catalog, other relevant catalogs, and a library of GLAST and previous gamma-ray results. Finally, GSSC scientists will provide expertise and advice, as needed. Investigators will request and receive assistance by E-mail, which will be logged. It is anticipated that the need for human assistance will be greatest early in the mission, and will taper off as on-line documentation is developed to answer the most frequently asked questions.

6.4.4 LEVEL 2 SCIENTIFIC ANALYSIS TOOLS

The Level 2 scientific analysis tools that derive results from count data will be developed by collaborations of GSSC scientists with the LAT and GBM teams. The GSSC and each IOC have convened a software working group (with HEASARC representation) for each instrument with a co-lead and equal representation from both the GSSC and the IOC. The software working groups will maintain the list of required software packages in §5.3, establish standards for this software, and set release dates for the software produced by members of the instrument teams and by GSSC scientists. The software will conform to the standards of the HEASARC by using FITS format files for I/O, utilizing PIL parameter files, and being mainly built of simple programs that can be run from a command line (see §6.5.2.1). The scientific tools will not require expensive proprietary software, and will run on the computer platforms common to the astronomical community. Basic documentation will accompany the software describing the applicability of the underlying methodology, the algorithms implemented, and the use of the code. Although the instrument teams are responsible for managing the development of the analysis tools, ultimately the GSSC is responsible for ensuring that the full set of tools defined in §5.3 is available at launch, and that these tools conform to the I/O standards and data formats (e.g., FITS) of the HEASARC. The software tools will be compatible with the norms of the astronomical community so that GLAST data can be combined with the data from other missions. To minimize the expense of reinventing software, the GSSC will work with the HEASARC to reuse software developed for past missions. The GSSC will also ensure that these tools are fully documented both as to their use and the underlying methodology.

6.4.5 MISSION SUPPORT

A TOO may be considered because: an approved GI's TOO criteria have been satisfied; a source is undergoing an extreme variation (e.g., a giant radio flare); or a scientific discovery or development justifies an immediate observation. TOO requests may be submitted to the Project Scientist through the GSSC website, or may be initiated by a source meeting the predetermined (e.g., through a GI proposal) LAT flux or flux derivative criteria. The Project Scientist (or his/her designee) will ask the GSSC whether a TOO is feasible. The GSSC will consider observational constraints (if any) and the impact on the timeline. Should the Project Scientist (or his/her designee) decide to declare a TOO, the GSSC will send the MOC a TOO order with the source coordinates and observation durations within 2 hours after the Project Scientist's approval.

The GSSC will assist the project scientists in organizing the meetings of GLAST-related committees such as the Timeline Committee and the Users' Committee (see below), as well as scientific workshops and conferences the project will convene.

6.4.6 STANDARD PROCESSING

The GSSC will process the Level 1 data to generate a number of standard products. Periodically skymaps of the counts from the entire sky and selected regions (e.g., the Galactic Center) will be produced and posted on the GSSC website. Similarly, exposure maps will be calculated and made available. The GSSC will also monitor a small number of strong sources, and post the resulting lightcurves on the GSSC website.

Under normal circumstances the GSSC will not perform Level 1 processing for either instrument. However, in case of an emergency, the GSSC will have current Level 1 processing pipelines installed on the GSSC servers as backups for the IOCs. A pipeline will not be operated without the concurrence and supervision of the relevant IOC. An GSSC scientist and a programmer will be familiar with the operation of the pipeline and with the methods it implements.

In conjunction with the other ground system elements (e.g., the MOC and the IOCs), the GSSC will test the major components of the ground system software. Thus the GSSC will participate in tests of this software to ensure that data will flow properly within and among the various ground system elements, and that the software packages perform properly. These tests will be described in the Ground System Test Plan. The GSSC will assist in validating the output of the Level 1 processing pipelines, and will challenge the science analysis tools with simulated data generated by the IOCs.

6.4.7 DATABASES AND ARCHIVING

The GSSC is responsible for maintaining databases of the various levels of observational and spacecraft data, the calibrations and software for use during the mission. Ultimately, the GSSC is responsible for archiving these data in the HEASARC, NASA's designated repository for gamma-ray data. All the data products in §5 that are transmitted to the GSSC by the MOC, LIOC, or GIOC, or that are produced at the GSSC, will be preserved in GSSC databases. For efficiency, the GSSC will follow HEASARC standards in constructing its databases and software. The GSSC's software will be run on HEASARC servers and the databases will reside on disks mounted on HEASARC servers (see §6.5). Consequently, after the end of the GLAST mission when the GSSC is disbanded, the GLAST databases will remain a permanent part of the HEASARC's databases. During the mission both GSSC and HEASARC software may access the GLAST databases.

While the IOCs will transmit the data listed in §5 in FITS files, or in a form easily converted into FITS format, the IOCs may elect to store and use this data in other formats. Similarly, although the GSSC will ultimately produce databases in a format and architecture the HEASARC will maintain after the mission, during the mission the GSSC may construct databases with an architecture optimized for specific uses, e.g., distributed over a multi-processor system.

6.4.8 RELATIONSHIP TO LHEA

While the GLAST GSSC will be a distinct entity dedicated to serving the GLAST user community, it will be part of the LHEA's OGIP. OGIP coordinates all guest observer programs within LHEA, and consists of the HEASARC and support centers for other missions that will operate concurrently with GLAST such as *INTEGRAL*, *Swift*, *XMM-Newton*, *Astro-E2* and *RXTE*. By co-locating the GLAST GSSC with other support centers and the HEASARC, the GSSC will use common resources such as web services, archival services, data backup, database servers and data/software standards. In addition the integrated astrophysics archive and software environment developed by the HEASARC in collaboration with other NASA data centers fosters a multi-mission approach. The responsibilities of the HEASARC to the GLAST GSSC are described in §6.5.

6.5 THE HIGH ENERGY ASTROPHYSICS SCIENCE ARCHIVE RESEARCH CENTER (HEASARC)

6.5.1 CONTEXT

The HEASARC is one of three NASA wavelength-specific research archives; the others are the Infrared Science Archive (IRSA) for infrared data and the Multimission Archive at Space Telescope science institute (MAST) for UV/optical data. The National Space Science Data Center (NSSDC) is the "deep archive." These centers support active missions and sustain in usable form archival data from missions that have ended. The archives are co-located with scientists actively undertaking research, connecting the data with the necessary science expertise. The multi-mission approach to the archives leads to cost savings and a uniform analysis environment for future missions by reusing software and archive resources. These data centers are currently coordinating data, software and media standards for space astrophysics.

Thus the HEASARC maintains and disseminates data from previous and current high energy astrophysics missions, and provides software and technical expertise for the analysis of the datasets produced by these missions. The community is aided by the HEASARC's catalogs of observations and library of ancillary information. Considerable cost and time savings have been realized by new missions (e.g. *RXTE*) using the HEASARC FITS data standards, existing software (e.g., HEAsoft) and Web/archive services that the HEASARC provides (e.g., Browse).

6.5.2 SUPPORT OF THE GSSC

The GSSC will maintain its databases and its website on HEASARC servers, and will avail itself of the HEASARC archives and software infrastructure. When the GSSC is disbanded at the end of the mission, the GSSC's databases will remain in the HEASARC as the GLAST mission's permanent archives. The "databases" and "archives" will be the same entities, with the first term used during the mission, and the latter after the mission. The following sections detail the HEASARC's responsibilities to the GSSC.

6.5.2.1 INFRASTRUCTURE

The HEASARC will provide and maintain the archive and software infrastructure necessary for the analysis of GLAST data and the integration of this data into the HEASARC's multi-mission system. The HEASARC standards are found online at http://heasarc.gsfc.nasa.gov/docs/heasarc/ofwg/ofwg_recomm.html. Where necessary, the HEASARC's system will expand to accommodate the GLAST data and its analysis software.

Thus the HEASARC will support standards and software for archiving the GLAST data. In particular, the HEASARC will support the archiving of event lists and will incorporate the tools necessary to extract events from such lists into the HEASARC's on-line browse software. These tools may originate in the LAT team or the GSSC, but the HEASARC will be responsible for their integration into the HEASARC's system.

The Level 2 analysis software will conform to the requirements developed by the GSSC-IOC software working groups. The Level 2 software will support FITS I/O conforming to HEASARC keyword standards. The IOCs and the GSSC will develop GLAST-specific analysis tools, many of which will support multi-mission analysis. During the mission these tools will be provided to GLAST investigators through the GSSC's website, but the HEASARC will integrate them into the general HEAsoft system.

The calibration data necessary to generate the IRFs will reside in the CALDB system. Consequently the HEASARC will provide and maintain the CALDB infrastructure and will augment this structure to accommodate GLAST's needs.

6.5.2.2 SERVERS

The HEASARC will provide and maintain the servers used by the GSSC to serve the investigator community, at no cost to the GLAST project, except for a multi-processor cluster the

GSSC will use for searching the LAT photon database. These are the servers that run the GSSC's databases, host the GSSC's website and communicate with the investigator community. The GSSC's disks will be mounted to these servers.

6.5.2.3 DISK SPACE

The GSSC will purchase and maintain the disks necessary to maintain the GSSC databases and website. The FITS files with investigator data will reside on these disks before the investigators FTP them to the investigators' home institution. These disks will be mounted on the servers that the HEASARC will provide for the GSSC, and therefore must be compatible with other HEASARC software and hardware. Procurement of these disks will begin at least nine months before launch. When the GSSC is disbanded, ownership of these disks and the data they contain will be transferred to the HEASARC.

6.6 ASSOCIATED ORGANIZATIONS

<u>The NASA HQ's Astronomy and Physics Division</u> within the Office of Space Science is responsible for all post-launch GLAST Mission science operations and provides funds for the GI Program and NASA-funded portions of mission operations and data analysis.

<u>The Office of Science of the U.S. Department of Energy (DOE)</u> provides funds to SU-SLAC in support of data reduction at the LIOC.

In addition to the organizations that are established and staffed on a full-time basis, there are working groups, committees and teams that meet periodically to assist in the development and support of the GLAST GI Program. These groups include representatives of NASA HQ, the Project, the instrument teams and potential GIs from the scientific community.

<u>The GLAST Science Working Group</u> (SWG) is responsible for maintaining a broad and critical scientific overview of GLAST's development. The SWG advises the GLAST project of new developments in related scientific fields, and reviews documents that could affect the scientific productivity of the mission (e.g., the Science Requirements Document, this PDMP, the Mission Science Plan).

<u>The GLAST Users' Committee</u> will provide input to the GLAST Program Scientist at NASA Headquarters on details of policies to adopt for the GI Program. The GLAST Project Scientist is responsible for implementing the policies developed by NASA HQs based on the recommendations of the Users' Committee.

<u>The GLAST Timeline Committee</u> will develop the annual observing plan for the operations of the GLAST Observatory (see §6.4.2). The Timeline Committee allocates observing time to GI proposed observations following guidelines established by the GI Program proposal peer review process. This committee must consider all spacecraft and instrument constraints and the observing requirements of the instruments to develop an integrated spacecraft pointing profile and instrument operation profiles to make the most efficient use of observing time on orbit.

<u>The GLAST Operations Working Group</u> gives expert technical advice on mission operations, both in the near and far future. This group will advise the NASA HQ's GLAST

Program Scientist through the GLAST Project Scientist on data operations issues throughout the operational years of the GLAST Mission.

The Pulsar Committee will coordinate the campaign to observe pulsars GLAST might detect and to extract their ephemerides.